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M.Sc. I Semester

Practical Physics I



DEPARTMENT OF PHYSICS

SCHOOL OF SCIENCES

UTTARAKHAND OPEN UNIVERSITY

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PRACTICAL PHYSICS I



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Experiment 1:

STUDY OF RLC CIRCUIT WITH AN AC SOURCE USING PHASE DIAGRAM

Structure

1.1 Object

1.2 Introduction

1.3 Apparatus

1.4 Theory and Formula Used

1.5 Procedure

1.6 Observation

1.7 Calculation

1.8 Result

1.9 Precautions and Sources of Error

1.10 Summary

1.11 Glossary

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1.13 Viva-voce Questions and Answers

1.1 OBJECT

To study R-L-C series circuits (AC).

1.2 INTRODUCTION. An RLC circuit is an electrical circuit consisting of a resistor (R), an inductor (L), and a capacitor (C), connected in series or in parallel. The name of the circuit is derived from the letters that are used to denote the constituent components of this circuit, where the sequence of the components may vary from RLC.

The circuit forms a harmonic oscillator for current, and resonates in a similar way as an LC circuit. Introducing the resistor increases the decay of these oscillations, which is also known as damping. The resistor also reduces the peak resonant frequency. Some resistance is unavoidable in real circuits even if a resistor is not specifically included as a component. An ideal, pure LC circuit exists only in the domain of superconductivity.

RLC circuits have many applications as oscillator circuits. Radio receivers and television sets use them for tuning to select a narrow frequency range from ambient radio waves. In this role, the circuit is often referred to as a tuned circuit. An RLC circuit can be used as a band-pass filter, band-stop filter, low-pass filter or high-pass filter. The tuning application, for instance, is an example of band-pass filtering. The RLC filter is described as a second-order circuit, meaning that any voltage or current in the circuit can be described by a second-order differential equation in circuit analysis.

1.3 APPARATUS

1. Single phase dimmer- stat
2. Ammeter (AC)
3. Voltmeter (AC)
4. Rheostat
5. Inductor
6. Capacitor
7. MultiFunction Meter

1.4 THEORY AND FORMULA USED

We know that changing magnetic flux can induce an emf according to Faraday's law of induction. In particular, if a coil rotates in the presence of a magnetic field, the induced emf

varies sinusoidally with time and leads to an alternating current (AC), and provides a source of AC power. The symbol for an AC voltage source is



An example of an AC source is

$$V(t) = V_0 \sin \omega t$$

where the maximum value V_0 is called the amplitude. The voltage varies between V_0 and $-V_0$ and since a sine function varies between +1 and -1, a graph of voltage as a function of time is shown in sinusoidal as shown in Figure 1.

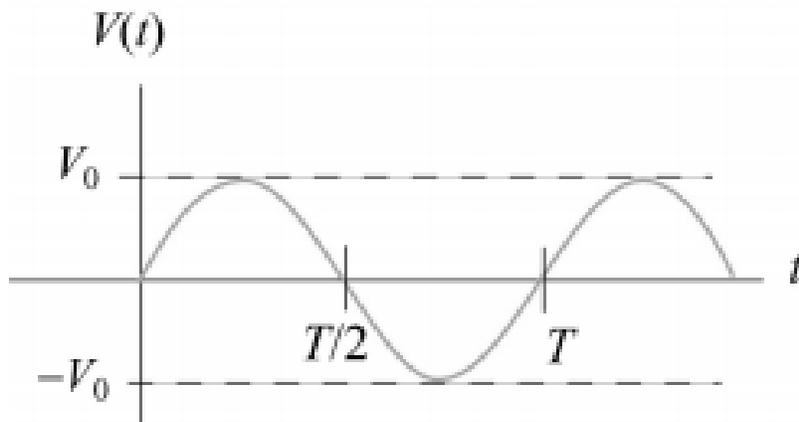


Figure 1: Sinusoidal voltage source.

When a voltage source is connected to an RLC circuit, energy is provided to compensate the energy dissipation in the resistor, and the oscillation will no longer damp out. The oscillations of charge, current and potential difference are called driven or forced oscillations.

After an initial “transient time,” an AC current will flow in the circuit as a response to the driving voltage source. The current, written as

$$I(t) = I_0 \sin(\omega t - \phi)$$

will oscillate with the same frequency as the voltage source, with an amplitude I_0 and phase ϕ that depends on the driving frequency.

The RLC Series Circuit

Consider now the driven series RLC circuit shown in Figure 2.

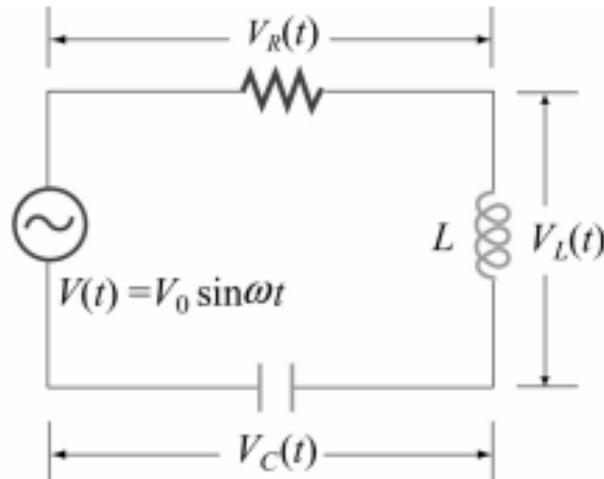


Figure 2: Driven series RLC circuit.

Applying Kirchhoff's loop rule, we obtain

$$V(t) - V_R(t) - V_L(t) - V_C(t) = V(t) - IR - L \frac{dI}{dt} - \frac{Q}{C} = 0$$

which leads to the following differential equation:

$$L \frac{dI}{dt} + IR + \frac{Q}{C} = V_0 \sin \omega t$$

Assuming that the capacitor is initially uncharged so that $I = +dQ / dt$ is proportional to the increase of charge in the capacitor, the above equation can be rewritten as

$$\boxed{L \frac{d^2 Q}{dt^2} + R \frac{dQ}{dt} + \frac{Q}{C} = V_0 \sin \omega t}$$

One possible solution to the above equation is

$$Q(t) = Q_0 \cos(\omega t - \phi)$$

The corresponding current is

$$I(t) = +\frac{dQ}{dt} = I_0 \sin(\omega t - \phi)$$

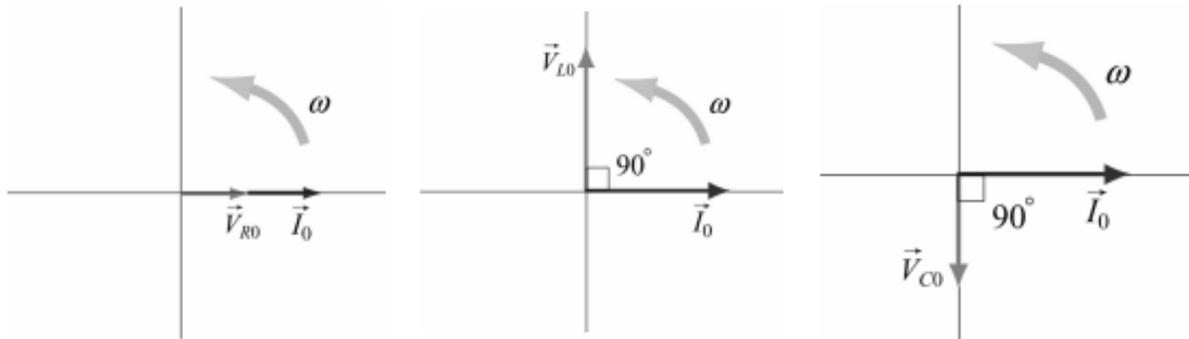


Figure 3: Phasor diagrams for the relationships between current and voltage in (a) the resistor, (b) the inductor, and (c) the capacitor, of a series RLC circuit.

From Figure 3, the instantaneous voltages can be obtained as:

$$\begin{aligned} V_R(t) &= I_0 R \sin \omega t = V_{R0} \sin \omega t \\ V_L(t) &= I_0 X_L \sin \left(\omega t + \frac{\pi}{2} \right) = V_{L0} \cos \omega t \\ V_C(t) &= I_0 X_C \sin \left(\omega t - \frac{\pi}{2} \right) = -V_{C0} \cos \omega t \end{aligned}$$

The sum of all three voltages is equal to the instantaneous voltage supplied by the AC source:

$$V(t) = V_R(t) + V_L(t) + V_C(t)$$

Using the phasor representation, the above expression can also be written as

$$\vec{V}_0 = \vec{V}_{R0} + \vec{V}_{L0} + \vec{V}_{C0}$$

as shown in Figure 4. Again we can see that current phasor leads the capacitive voltage phasor by $\pi/2$ but lags the inductive voltage phasor by $\pi/2$. The three voltage phasors rotate counterclockwise as time passes, with their relative positions fixed.

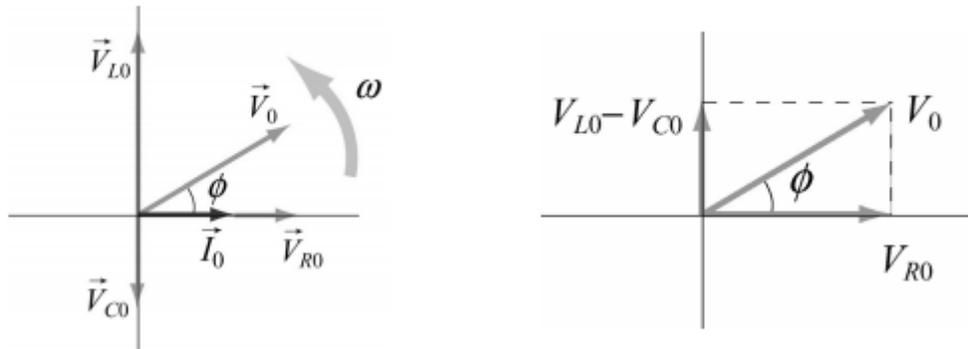


Figure 4: (a) Phasor diagram for the series RLC circuit. (b) voltage relationship.

1.5 PROCEDURE

1. Make the connections as per the circuit diagram.
2. Set the rheostat for maximum resistance.
3. Set the dimmerstat to zero output & switch on the mains.
4. Adjust the variac so as to apply a suitable voltage to the circuit, measure the current I & voltages V_R , V_L , V_C and supply voltage V_S at the output of variac.
5. Take different sets of reading by applying different voltages.
6. Make the calculations as shown in table.
7. Observe the waveform on CRO.

Procedure for Drawing Series circuit phasor diagram:

1. Choose suitable scale for voltages & voltage drops.
2. Take current I as reference & draw V_R in phase with I ($V_R = OA$).
3. Draw the arcs $AB = V_L$ & $OB = V_{RL}$ intersecting each other at point B
4. Join A with B & O with B .
5. Draw $OD = V_C$ at an angle 90° lagging to I .
6. Draw a vertically downwards line from B i.e. $BC = V_C = OD$. Join $OC = V_S$
7. Find the p.f. angle ϕ between V_S & I .

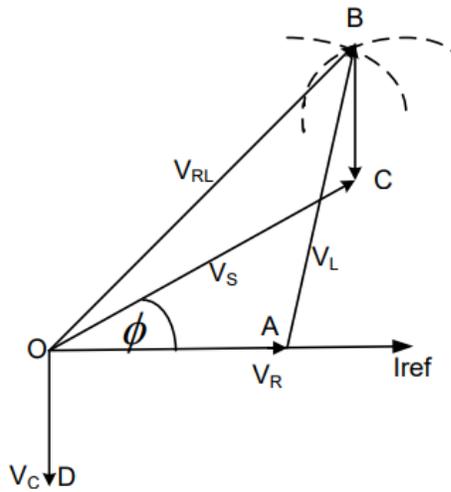


Figure 5

1.6 OBSERVATION

RLC Series circuit:

Internal resistance of the coil =

Sr. No.	Position of rheostat	V _s volt	I Amp	V _R volt	V _L Volt	V _C volt	V _{RL} volt	P.f. of ckt
1	Middle position	100V						
2	Maximum position	100V						

1.7 CALCULATION

For RLC Series circuit:

Sr .N o.	$R = \frac{V_R}{I}$	$Z_L = \frac{V_L}{I}$	$X_L = \sqrt{Z_L^2 - r^2}$	$|Z = \frac{V_S}{I}|$	ϕ from calculations $\phi = \cos^{-1} \left(\frac{R+r}{Z} \right)$	ϕ from phaso r dig r	ϕ from p.f. mete r

1.8 RESULT

There should be a good match between the phases ϕ from theoretical calculations, from phasor diagram and from p. f. meter.

1.9 PRECAUTIONS AND SOURCES OF ERROR

1. When working with resonant circuits, or electrical circuits, you must be aware of the potentially high voltages.

1.10 SUMMARY

In RLC circuit, the most fundamental elements like resistor, inductor and capacitor are connected across a voltage supply. All these elements are linear and passive in nature; i.e. they consume energy rather than producing it and these elements have a linear relationship between voltage and current. There are number of ways of connecting these elements across voltage supply, but the most common method is to connect these elements either in series or in parallel. The RLC circuit exhibits the property of resonance in same way as LC circuit exhibits, but in this circuit the oscillation dies out quickly as compared to LC circuit due to the presence of resistor in the circuit.

When a resistor, inductor and capacitor are connected in series with the voltage supply, the circuit so formed is called series RLC circuit. Since all these components are connected in series, the current in each element remains the same.

The total voltage in RLC circuit is not equal to algebraic sum of voltages across the resistor, the inductor and the capacitor; but it is a vector sum because, in case of resistor the voltage is in-

phase with the current, for inductor the voltage leads the current by 90° and for capacitor, the voltage lags behind the current by 90° . So, voltages in each component are not in phase with each other; so they cannot be added arithmetically. The figure below shows the phasor diagram of series RLC circuit. For drawing the phasor diagram for RLC series circuit, the current is taken as reference because, in series circuit the current in each element remains the same and the corresponding voltage vectors for each component are drawn in reference to common current vector.

$$V_S^2 = V_R^2 + (V_L - V_C)^2 \text{ (if } V_L > V_C \text{)}$$

$$V_S^2 = V_R^2 + (V_L - V_C)^2 \text{ (if } V_L < V_C \text{)}$$

$$\text{Where } V_R = IR, V_L = IX_L, V_C = IX_C$$

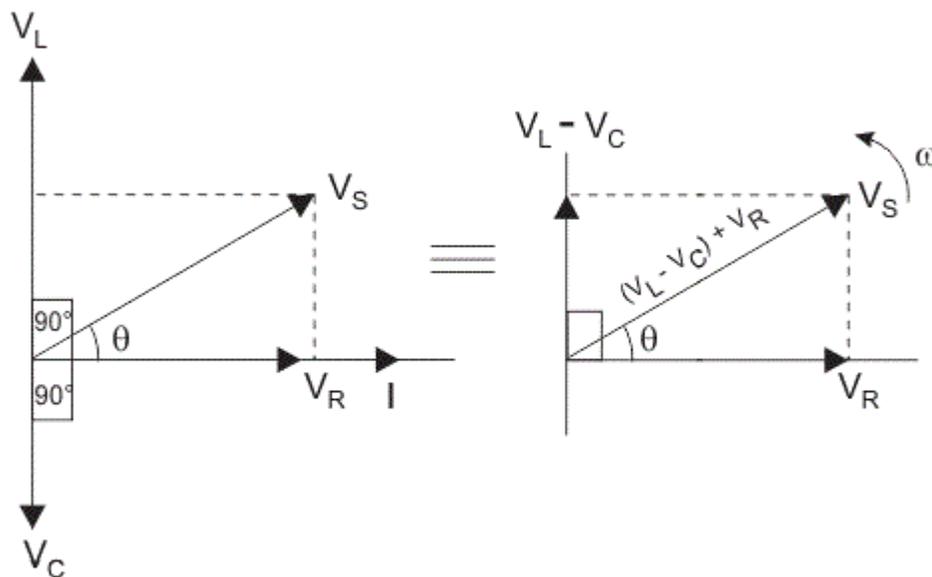


Figure 6: Phasor diagram for RLC circuit.

1.11 GLOSSARY

Capacitor – A capacitor is one of the fundamental circuit elements. There are three primary elements of electric circuits, resistor, inductor and capacitor. The capacitor in an electrical circuit behaves as a charge storage device. It holds the electric charge when we apply a voltage across it, and it gives up the stored charge to the circuit as when required.

The most basic construction of a capacitor consists of two parallel metallic plates separated by a dielectric material. When we connect a voltage source across the capacitor, the capacitor plate attached to the positive terminal of the source becomes positively charged, and the capacitor plate connected to the negative terminal of the source becomes negatively charged. Because of the presence of dielectric in between the plates, ideally, no charge can migrate from one plate to other.

Inductance – If a changing flux is linked with a coil of a conductor there would be an emf induced in it. The property of the coil of inducing emf due to the changing flux linked with it is known as inductance of the coil. Due to this property all electrical coil can be referred as inductor. In other way, an inductor can be defined as an energy storage device which stores energy in form of magnetic field.

Microammeter – an instrument for measuring extremely small electric currents, calibrated in microamperes.

Resistor – The resistor is a passive electrical component to create resistance in the flow of electric current. In almost all electrical networks and electronic circuits they can be found. The resistance is measured in ohms.

1.12 REFERENCES

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2. University Practical Physics, D. C. Tayal – Himalaya Publishing House, 2000

1.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. How does the impedance for a capacitor vary with angular frequency?

Ans: Impedance for a capacitor varies inversely with the capacitance and angular frequency. This means when we have a large angular frequency impedance will be very small, conversely for a very small angular frequency impedance will be large.

2. How does the impedance of inductor vary with angular frequency?

Ans: The impedance of the inductor must include both the resistance of the inductor and its natural impedance. Since impedance varies proportionally with angular frequency, a large frequency translates into a large impedance and a small frequency would result in a small impedance.

3. What is the impedance for a resistor?

Ans: Resistor's impedance is simply its resistance.

4. What is a phasor diagram?

Ans: Phasor Diagrams are a graphical way of representing the magnitude and directional relationship between two or more alternating quantities.

5. What are some of the applications of series RLC circuit?

Ans: Following are some of the applications:

- It acts as a variable tuned circuit
- It acts as a low pass, high pass, band pass, band stop filters depending upon the type of frequency.
- The Circuit also works as an oscillator
- Voltage multiplier and pulse discharge circuit

Experiment 2:

ABSOPTION SPECTRA OF KMNO_4 USING SINGLE BEAM SPECTROPHOTOMETER

Structure

2.1 Object

2.2 Introduction

2.3 Apparatus

2.4 Theory and Formula Used

2.5 Procedure

2.6 Observation

2.7 Calculation

2.8 Result

2.9 Precautions and Sources of Error

2.10 Summary

2.11 Glossary

2.12 References

2.13 Viva-voce Questions and Answers

2.1 OBJECT

To use spectrophotometry to prepare a calibration curve for the quantitative analysis of KMnO_4 .

After completing this experiment, the student should be able to:

1. Prepare standard solutions of potassium permanganate.
2. Construct calibration curve based on Beer's Law.
3. Use Beer's Law to determine molar absorptivity.
4. Explain the fundamental principal behind spectrophotometric analysis

2.2 INTRODUCTION

Most analytical methods require calibration (a process that relates the measured analytical signal to the concentration of analyte, the substance to be analyzed). The three most common analysis methods include the preparation and use of a calibration curve, the standard addition method, and the internal standard method. In this experiment we will use spectrophotometry to prepare a calibration curve for the quantitative analysis of KMnO_4 .

2.3 APPARATUS

UV/VIS spectrophotometer and polystyrene cuvettes, two 100 mL volumetric flask, 1000 μL micropipette, 100 μL pipet, Hot plate, solid KMnO_4 , one 10 mL graduated cylinders, six 10 mL volumetric flasks, two 125 mL Erlenmeyer flasks or 150 mL beakers

2.4 THEORY AND FORMULA USED

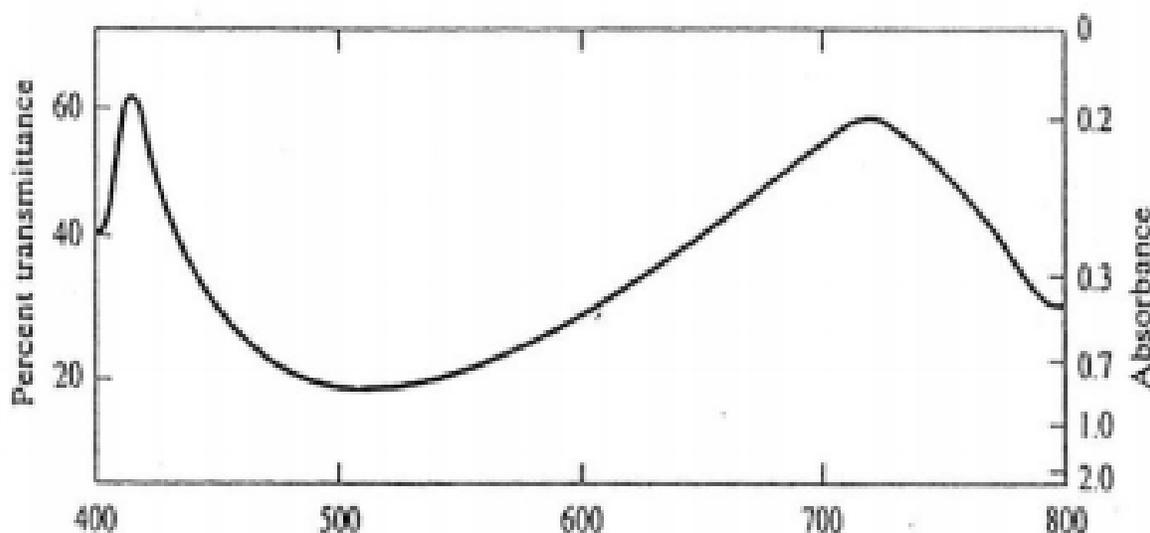
Spectrophotometry is a technique that uses the absorbance of light by an analyte (the substance to be analyzed) at a certain wavelength to determine the analyte concentration. UV/VIS (ultra violet/visible) spectrophotometry uses light in UV and visible part of the electromagnetic spectrum. Light of this wavelength is able to effect the excitation of electrons in the atomic or molecular ground state to higher energy levels, giving rise to an absorbance at wavelengths specific to each molecule. The complex formed between ASA and Fe^{3+} is intensely violet coloured, and therefore can be determined by spectrophotometry using the visible part of the electromagnetic spectrum.

The human eye is able to "see" light in the wavelength range 400-700 nm (nanometer or 10^{-9} m). To the human eye, wavelength appears as colour, as shown in the following table

Table 1: Correlation between wavelength, colour, and complementary colour.

Wavelength, nm	Colour	Complementary colour
400-430	Violet	Yellow-green
430-490	Blue	Yellow
490-550	Green	Purple
550-590	Yellow	Blue
590-630	Orange	Green-blue
630-700	Red	Blue-green

When we see an object as purple, in fact it absorbs light in the “green” region of the spectrum: only blue and red wavelengths reach the eye, which we experience as the purple colour. The ASA-Fe³⁺ complex formed in the analysis of aspirin absorbs wavelengths in the blue, green and yellow regions of the spectrum, as shown in Figure 1. Only violet and red light are “transmitted”. As a result, the human eye sees the transmitted light as a mixture of violet and red, which we experience as a deep purple.

**Figure 5: The absorption spectrum of the Fe³⁺-salicylate complex.**

In Figure 1, note that % Transmittance T is plotted on the left (linear scale), Absorbance A on the right (logarithmic scale). The absorbance maximum is at approximately 510 nm (λ_{\max}).

The spectrophotometer takes the place of the human eye by accurately measuring the intensity of the light transmitted at each wavelength. For spectrophotometry in the visible region the light source is a common tungsten light bulb emitting “white” light. The light is collimated and focused on an entrance slit, and then falls on a monochromator, that separates the white light in its constituent wavelengths.

The monochromator can be a glass prism, but in modern instruments it will be a grating. From the monochromator the light is sent through the sample, and finally reaches a photocell that measures the intensity of the light at each specific wavelength.

Spectrophotometers have many different designs. In the simplest instrument, for each wavelength λ set by the monochromator, the user first inserts a blank solution in place of the sample. The photocell then records the intensity at that wavelength. This intensity is called $I_0(\lambda)$. Next the blank solution is replaced by the sample solution, the photometer measures the new intensity called $I(\lambda)$. The Transmittance, T is then displayed on the screen or spectrophotometer output:

$$T(\lambda) = \frac{I(\lambda)}{I_0(\lambda)} \quad (1)$$

Often the Transmittance is expressed as a percentage:

$$\%T(\lambda) = \frac{I(\lambda)}{I_0(\lambda)} \times 100 \% \quad (2)$$

This procedure is then repeated for a number of wavelengths.

More sophisticated instruments “scan” the spectrum over the required wavelength range automatically, and record the transmittance as a function of wavelength. In a “double beam” scanning spectrophotometer, part of the light is reflected to a separate blank cell, and the intensities I and I_0 are measured simultaneously at each wavelength, and automatically compared to yield a direct output of T vs λ . Another modern form of the UV/VIS spectrophotometer is the “Diode Array” spectrophotometer. In this instrument the photocell, which measures light intensity at one wavelength at a time, is replaced by a CCD detector similar to the detector in your digital camera, and the instrument can record the spectrum over the full wavelength range (typically 200–700 nm) within one second!

In each fractional layer of the sample the intensity of the incoming light will decrease proportionally to the concentration of the analyte. As a result, the Transmittance T decreases exponentially with increasing pathlength l . This is expressed in the Beer Lambert law, which states:

$$-\log \frac{I}{I_0} = \epsilon \cdot l \cdot C \quad (3)$$

ϵ is called the “Molar Absorptivity” of the compound. It is a function of wavelength specific for each molecule. With the pathlength l normally given in cm, and C in Molarity units, mol/L ϵ has the units $L \cdot mol^{-1} \cdot cm^{-1}$. If alternatively C is in mol/mL, then ϵ will have the units $cm^2 \cdot mol^{-1}$.

The Absorbance, A , is defined as

$$A = -\log \frac{I}{I_0} \quad (4)$$

Thus, the Beer-Lambert law, more commonly called Beer’s law, can be written as:

$$A = \epsilon \cdot l \cdot C \quad (5)$$

Finally, the relation between A and T is given by:

$$A = -\log T \quad (6)$$

Note that A is a dimensionless quantity. Because A is directly proportional to the analyte concentration, it is more often used than T or % T . Most spectrometers can record either A , T , or % T for a given wavelength.

The calibration curve method

To use the calibration curve technique, several standards containing exactly known concentrations of the analyte are introduced into instrument, and the instrumental response is recorded. Ordinarily this response is corrected for instrument output obtained with a blank. Ideally, the blank contains all of the components of the original sample except for the analyte. The resulting data are then plotted to give a graph of corrected instrument response versus analyte concentration, and this graph in turn can be used to find the concentration of an unknown.

Solutions of analyte may absorb light of different wavelengths. When the analyte to our eyes is a colored solution, this means that out of the white light visible to the eye certain wavelengths are absorbed by the analyte molecules, letting the other colors of the white light pass through, giving rise to the characteristic color of the analyte in solution. For instance, the analyte in this experiment, potassium permanganate or $KMnO_4$ absorbs light in the green region of the visible spectrum, letting red light and blue light pass through. The mixture of blue and red is perceived by the eye as the typical purple color of $KMnO_4$.

A spectrum shows how much light is absorbed for a range of wavelengths. In UV/VIS spectrophotometry we plot the Absorbance A of a solution (A is a measure of how much light is

absorbed, see below), against the wavelength of the light reaching the solution, λ . This is called the absorption spectrum.

The higher the analyte concentration, the lighter at a certain wavelength will be absorbed. The relation between Absorbance A and analyte concentration C is given in equation 5:

In a UV/VIS spectrophotometer a light source emits light at all wavelengths of the UV and visible spectrum. Via a system of mirrors the light is guided to a monochromator that selects light of only a certain wavelength. After the monochromator, the light passes through the analyte sample solution held in a cuvette in the sample holder, and finally reaches the detector (a photocell), where the intensity of the light reaching it is measured, and recorded as the Absorbance A or the Transmission T (or %T). In this experiment we will only use the Absorbance at different wavelengths, $A(\lambda)$.

In a single beam spectrophotometer (as used in this experiment), we first place a cuvette filled with solvent only (water in this case), to measure the intensity of the light source at a certain wavelength. Next, we place a cuvette filled with sample solution in the cell holder. The instrument will record light intensity and absorbance relative to the light intensity passes through solvent (water) alone. This must be repeated at different wavelengths to obtain the spectrum of the dissolved solute ($A(\lambda)$ vs. λ).

From the spectrum we find the wavelength with the highest absorbance, the wavelength of the absorption peak, λ_{\max} . At this wavelength the spectrophotometric method is most sensitive for the analyte. Next, we determine the absorbance A at λ_{\max} for a number of standard solutions of different concentration, always starting with the lowest concentration. From these absorbance values, we plot a calibration curve for the analyte (KMnO_4 in our case), which we can then use to determine the concentration of an analyte solution of unknown concentration.

2.5 PROCEDURE

Preparing the stock solution and four standard solutions.

1. Preparation of 100 mL of a stock standard solution of 0.008M KMnO_4 : Accurately weigh 126 mg solid KMnO_4 . Transfer quantitatively to a 100 mL volumetric flask and fill to the mark with water. This is the stock solution.
2. Prepare four standards in 10 mL volumetric flask with concentrations of 0.00008 M (solution #1), 0.00016 M (solution #2), 0.0004 M (solution #3) and 0.0008 M (solution #4) by diluting the stock solution prepared in Step 1 as following.

For the 0.00008, 0.00016 and 0.0004 M standards use the 100 μL micropipettes (100 μL = 0.1 mL; calculate how many 100 μL samples stock solution are needed in each case) to make 10 mL standard solution. For the 0.0008 M standard use the 1 mL (1000 μL) micropipette, Mark the four 10 mL flasks with standard solutions #1-4 (lowest concentration #1 = 0.00008 M, highest concentration #4 = 0.0008 M).

Measuring the absorption spectrum and determining λ_{max} .

This part of the experiment may be done by all students together, with each pair of students determining the absorbance at one wavelength. Each pair of students should record all absorbance at each wavelength and draw the absorption spectrum.

3. Rinse one of the cuvettes with distilled water and fill it with water. Put the cuvette in the sample compartment. This is the reference solution. Set the wavelength to 400 nm, then set the Absorbance to zero.
4. Rinse a second cuvette once with distilled water and once with standard solution #1, then fill it with standard solution #1 (0.0008 M KMnO_4). Place the cell in the sample compartment, measure the Absorbance at 400 nm and record in your notebook.
5. Repeat this procedure (steps 3 and 4 above) for the two cuvettes at wavelengths 420, 440, 460,.....600 nm, first setting $A = 0$ for the cuvette with water, then measuring A for the cuvette with 0.0008 M KMnO_4 , recording the absorbance at each wavelength. Record in the data table.
6. Prepare a graph of absorbance A vs. wavelength λ and determine λ_{max} (maximum wavelength).

The calibration curve

7. Set the wavelength at 525 nm (λ_{max}). Place the cuvette with distilled water in the cell compartment and again set the Absorbance to zero.
8. Measure and record the Absorbance of each of the four standard solutions, starting with the most dilute standard. After each measurement, rinse the cuvette with the next standard, not with distilled water!
9. Draw a plot having X-axis as concentration (mole/L) and Y-axis as Absorbance at λ_{max} (525 nm).
10. Use Beer's law to calculate ϵ for KMnO_4 , given the cell width (path length l) to be 1 cm

2.6 OBSERVATION

1. Stock solution:

1. Mass of KMnO_4 =
2. Molar mass of KMnO_4 =
3. Moles KMnO_4 = mass/molar mass =
4. Molarity of stock solution = $\text{mol KMnO}_4/0.100\text{L}$ =

2. Preparation of standard solutions:

Standard solution 1 (dilute 1.0 mL stock to 10 mL).

KMnO_4 molarity = $(1.0/10) \times (\text{stock solution concentration}) =$ _____ mol/L

Same for concentrations of solutions “2”, “3” and “4” with 500, 200, and 100 μL stock.

Remember that 100 μL is 0.1 mL.

KMnO_4 molarity for standard solution 2 = _____ mol/L

KMnO_4 molarity for standard solution 3 = _____ mol/L

KMnO_4 molarity for standard solution 4 = _____ mol/L

3. The absorption spectrum of KMnO_4 :

S. #	Wavelength	Absorbance
1	400	
2	420	
3	440	
4	460	
5	480	
6	500	
7	520	
8	540	
9	560	
10	580	
11	600	

Make a graph of A vs λ at 20 nm wavelength intervals from 400 nm to 600 nm.

4. The calibration curve at $\lambda_{\text{max}} = 525 \text{ nm}$

Standard	Concentration	Absorbance
1		
2		
3		
4		

Make a graph of A (y-axis) vs M (x-axis).

2.7 CALCULATION

Calculation of the molar extinction coefficient ϵ at 525 nm.

Use the A-value of solution 1:

$$\epsilon = A/(C \cdot l), \text{ with } l = 1 \text{ cm } \epsilon = \underline{\hspace{2cm}}$$

2.8 RESULT

Example: how to make a graph in Excel.

Standard	Concentration	Absorbance
1	0.00008	0.124
2	0.00016	0.239
3	0.00040	0.614
4	0.00080	1.160

In Excel, enter the concentration values e.g. in cells b1-b4, and enter the absorbance values in cells c1-c4. Now continue as follows

1. Insert choose scatter then from the types of graphs choose the one with only your data points. Your graph will appear.
 2. Now you want to show the best straight line through the points:
 3. On “layout” select “trend line”, choose “linear”. The line will appear but it will not extend to the y-axis (where $x = 0$)
 4. Now right click on the line. Choose “format trend line”
 5. Under “forecast” click backward and 0.00008. Also click the box “display equation on chart”
- The final graph is shown below:

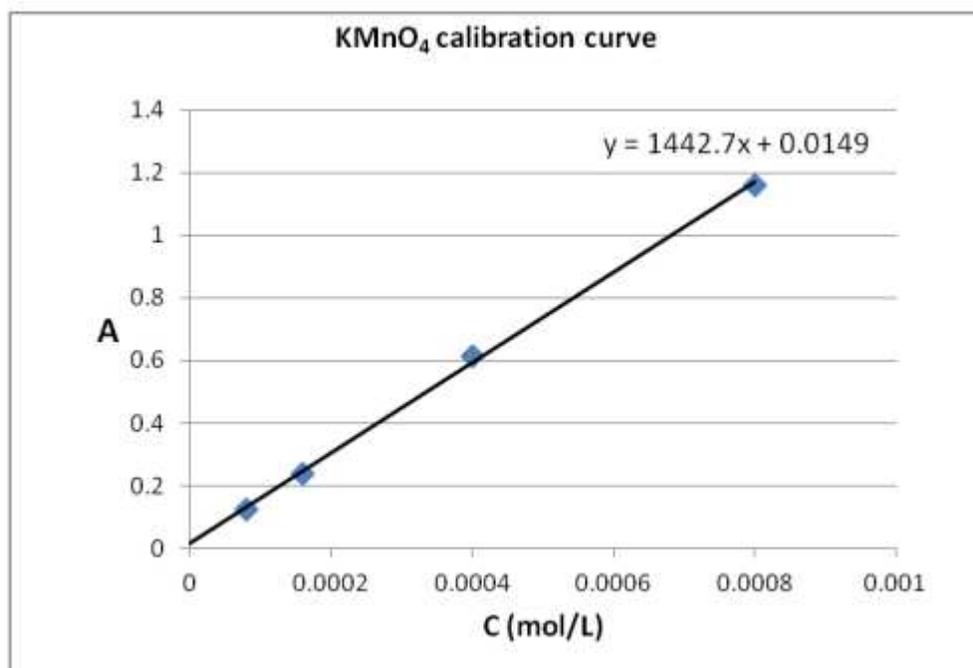


Figure 6: KMnO₄ calibration curve.

On the graph you can see that the trend line does not pass exactly through zero. This is as expected: it may be due to the statistics of the data point, which are not exactly on the straight line due to random errors in the concentration and/or the absorbance reading, or to the fact that

there is a remaining solution absorbance (relative to the blank) for the standards. For these reasons, you should not choose the “set intercept” box when formatting the trendline.

Finally, note that the trend line slope is the Molar Extinction Coefficient (Molar Absorptivity)! The equation $y = 1442.7x + 0.0149$ for this application should be read as $A = \epsilon.C + \text{constant}$, with the constant = intercept.

2.9 PRECAUTIONS AND SOURCES OF ERROR

1. The spectrophotometer is an expensive and sensitive instrument; it should be treated with care. Your laboratory instructor will demonstrate how to use it.
2. Prepare the stock solution and the standard solutions carefully.
3. Set the Absorbance to zero before measuring and record the Absorbance of each of the four standard solutions, starting with the most dilute standard first.

2.10 SUMMARY

A study of the interaction of light (or other electromagnetic radiation) with matter is an important and versatile tool for the scientist. Indeed, much of our knowledge of chemical substances comes from their specific absorption or emission of light. In this experiment, we are interested in analytical procedures based on the amount of light absorbed (or transmitted) as it passes through a sample.

Suppose you look at two solutions of the same substance, one a deeper color than the other. Your common sense tells you that the darker colored one is the more concentrated. In other words, as the color of the solution deepens, you infer that its concentration also increases. This is an underlying principle of spectrophotometry: the intensity of color is a measure of the amount of a material in solution.

A second principle of spectrophotometry is that every substance absorbs or transmits certain wavelengths of radiant energy but no other wavelengths. For example, chlorophyll always absorbs red and violet light, while it transmits yellow, green, and blue wavelengths. The transmitted and reflected wavelengths appear green—the color your eye “sees.” The light energy absorbed or transmitted must match exactly the energy required to cause an electronic transition (a movement of an electron from one quantum level to another) in the substance under consideration. Only certain wavelength photons satisfy this energy condition. Thus, the absorption or transmission of specific wavelengths is characteristic for a substance, and a spectral analysis serves as a “fingerprint” of the compound.

In recent years' spectrophotometric methods have become the most frequently used and important methods of quantitative analysis. They are applicable to many industrial and clinical problems involving the quantitative determination of compounds that are colored or that react to form a colored product.

2.11 GLOSSARY

Absorbance - Absorbance is defined as the negative logarithm of the transmittance, and you will note that absorbance and transmittance bear an inverse relationship.

Beer's Law (Beer-Lambert Law) – The amount of energy absorbed or transmitted by a solution is proportional to the solution's molar absorptivity and the concentration of solute.

In simple terms, a more concentrated solution absorbs more light than a more dilute solution does. Mathematical statement of Beer's law is $A = \epsilon lc$, where: A = absorption; ϵ = molar attenuation coefficient, l = path length (the thickness of the solution), and c = concentration of the solution.

Cuvette - a straight-sided clear container for holding liquid samples in a spectrophotometer or other instrument.

Illuminance – In photometry, illuminance is the total luminous flux incident on a surface, per unit area. It is a measure of how much the incident light illuminates the surface, wavelength-weighted by the luminosity function to correlate with human brightness perception.

Intensity – In physics, intensity is the power transferred per unit area, where the area is measured on the plane perpendicular to the direction of propagation of the energy. In the SI system, it has unit's watts per square metre.

Photometry – Photometry is the science of the measurement of light, in terms of its perceived brightness to the human eye.

Spectrophotometry – it is the quantitative measurement of the reflection or transmission properties of a material as a function of wavelength. It is more specific than the general term electromagnetic spectroscopy in that spectrophotometry deals with visible light, near-ultraviolet, and near-infrared, but does not cover time-resolved spectroscopic techniques.

Transmittance – We define transmittance as the ratio of the amount of light transmitted to the amount of light that initially fell on the surface.

2.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017
2. Practical Physics, Gupta and Kumar – Pragati Prakashan, Meerut, 1985

2.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. How does a spectrometer work?

Ans: The basic function of a spectrometer is to take in light, break it into its spectral components, digitize the signal as a function of wavelength, and read it out and display it through a computer. The first step in this process is to direct light through a fiber optic cable into the spectrometer through a narrow aperture known as an entrance slit. The slit vignettes the light as it enters the spectrometer. In most spectrometers, the divergent light is then collimated by a concave mirror and directed onto a grating. The grating then disperses the spectral components of the light at slightly varying angles, which is then focused by a second concave mirror and imaged onto the detector. Alternatively, a concave holographic grating can be used to perform all three of these functions simultaneously.

Once the light is imaged onto the detector the photons are then converted into electrons which are digitized and read out through a USB (or serial port) to a computer. The software then interpolates the signal based on the number of pixels in the detector and the linear dispersion of the diffraction grating to create a calibration that enables the data to be plotted as a function of wavelength over the given spectral range. This data can then be used and manipulated for countless spectroscopic applications.

2. What is the difference between spectroscopy and spectrophotometry?

Ans: The term spectroscopy is normally reserved for measurements of the electromagnetic spectrum. Words ending in -scopy mean "looking at" whereas words in -metry mean "measurement of". In practice, the two are used interchangeably, with the exception of mass spectrometry where the term "mass spectroscopy" is discouraged.

3. According to the Beer-Lambert Law absorbance is proportional to concentration at each wavelength. Could we choose any wavelength for quantitative estimations of concentration?

Ans: Theoretically, we can choose any wavelength for quantitative estimations of concentration. However, the magnitude of the absorbency is important, especially when you are trying to detect very small amounts of material. In the spectra above note that the distance between curves 1 and 2 is at a maximum at 525 nm, and at this wavelength the change in absorbance is greatest for a given change in concentration. That is, the measurement of concentration as a function of concentration is most sensitive at this wavelength. For this reason, we generally select the

wavelength of maximum absorbance for a given sample and use it in our absorbance measurements.

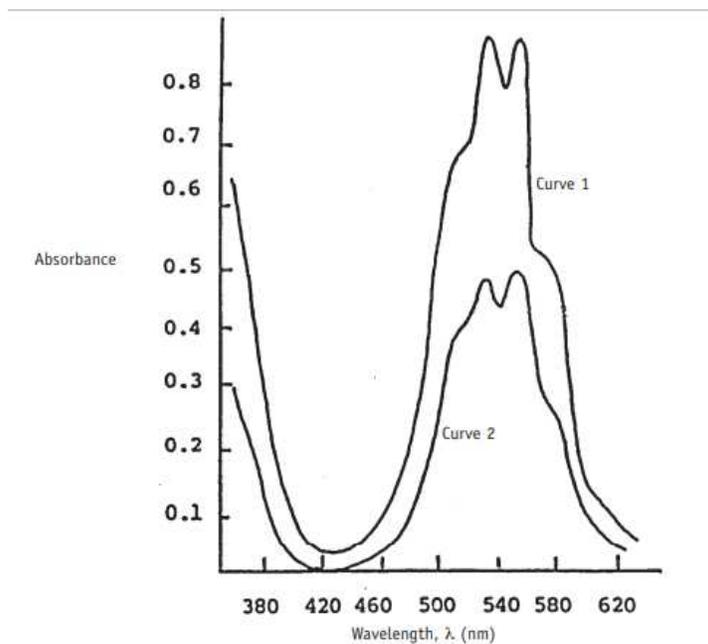


Figure 7: The absorption spectrum of solutions of potassium permanganate (KMnO₄) at two different concentrations. The solution for curve 1 has a higher concentration than that for curve 2.

Experiment 3:

YOUNG'S MODULUS WITH THE HELP OF INTERFERENCE METHOD

Structure

3.1 Object

3.2 Introduction

3.3 Apparatus

3.4 Theory and Formula Used

3.5 Procedure

3.6 Observation

3.7 Calculation

3.8 Result

3.9 Precautions and Sources of Error

3.10 Summary

3.11 Glossary

3.12 References

3.13 Viva-voce Questions and Answers

3.1 OBJECT

To determine Young's modulus and Poisson's ratio of a glass plate using Cornus method.

3.2 INTRODUCTION

This device is similar to Newton's Rings apparatus, except that an arrangement for loading the test piece is provided for carrying out Cornus interference studies. The objective of this experiment is to determine Poisson's ratio and Young's Modulus for different materials (glass, Perspex etc.) using interference method. Weights are positioned at both ends of the bar, causing it to bend longitudinally downward. A glass plate is placed on the bar to produce an interference pattern. By examining the interference pattern, extent of longitudinal and lateral bending can be determined. Thus, Poisson ratio and Young's modulus of the bar can be deduced.

When a plano-convex lens rests on a uniformly bent glass bar, an air film is formed between the two surfaces. Without adding any mass in the weight hanger we get circular rings. But as we uniformly add mass on the weight hangers, the beam bends and we get elliptical fringes.

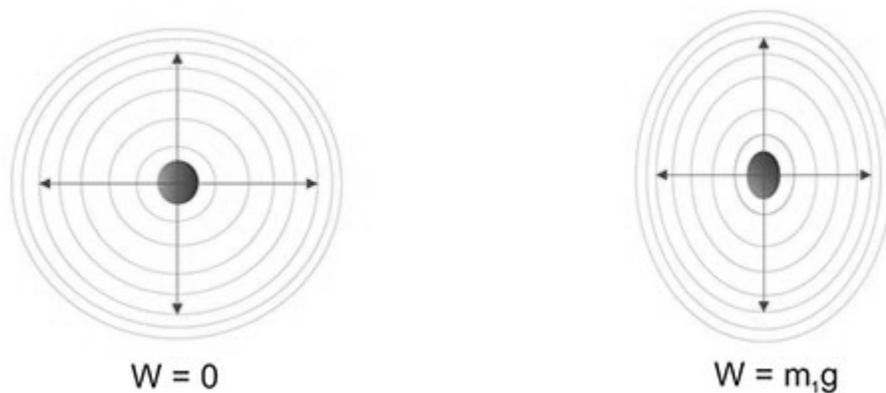


Figure 8: Cornus interference pattern and its longitudinal and lateral bending.

3.3 APPARATUS

1. Optically plane glass plate
2. Travelling Microscope
3. Sodium lamp
4. Glass beam
5. A square shaped glass slide

6. Slide caliper and screw gauge
7. Pair of knife edges, hangers, loads etc.

3.4 THEORY AND FORMULA USED

Young's modulus, also known as modulus of elasticity is an important characteristic of a material and is defined to be ratio of longitudinal stress and longitudinal strain and is given by

$$Y = \frac{F.L_0}{A.\Delta L} \quad \dots (1)$$

which has unit of Pressure (Pascal) and F , A , ΔL and L_0 are force, area, extension and initial length respectively. Young's modulus can be used to predict elongation or compression of an object as long as the stress is less than the yield strength of the material. Another important elastic constant is Poisson's ratio. When a sample of material is stretched in one direction it tends to get thinner in the other two directions.

Poisson's ratio is a measure of this tendency and is defined as the ratio of the strain in the direction of applied load to the strain in the transverse direction. A perfectly incompressible material has Poisson's ratio $\sigma = 0.5$. Most practical engineering materials have $0 \leq \sigma \leq 0.5$. For example, Poisson's ratio for cork, steel and rubber is 0, 0.3 and 0.5 respectively. Polymer foams have negative Poisson's ratio, when it is stretched it gets thicker in other direction.

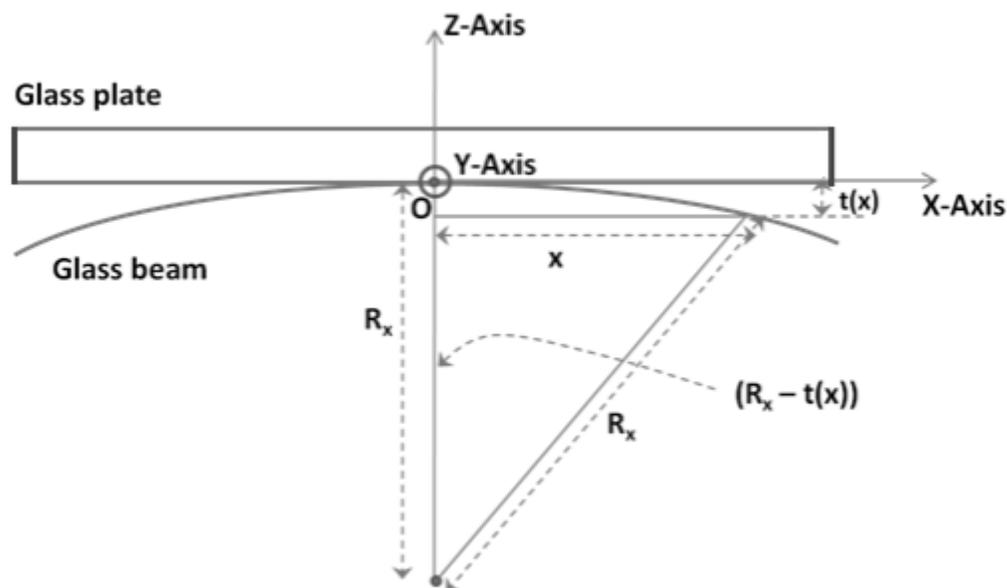


Figure 9: Geometry for obtaining interference fringes.

In an elegant experiment, Marie Alfred Cornu in the year 1869 first showed that the interference phenomenon in optics could be used for measuring deformation of a solid under load. At that time, it was very interesting to find that counting of interference fringes could provide information about Young's modulus and Poisson's ratio for a transparent material. The method proposed by Cornu employs a glass plate placed on top of a glass beam. When load is applied on both the sides of the glass beam, it gets deformed due to strain along the longitudinal direction (X-axis). Since the Poisson's ratio $\sigma \neq 0$, the glass beam will bend in the transverse direction (Y-axis). Thus, the beam deforms into the shape of horse saddle forming a thin film of air between them. When the film is illuminated by monochromatic light, interference occurs between the light reflected from the bottom of the glass plate and the top of the beam as shown in Figure 2.

Let 'x' and 'y' represent the coordinates along the longitudinal and the transverse directions with the middle point being the origin (O). Also, let R_x and R_y be the radius of curvature in longitudinal (X) and transverse (Y) directions respectively. In order to obtain the shape of the interference fringes, consider that the thickness of air film between the glass plate and the beam to be 't(x,y)' at appoint (x,y) in the XY-plane. First, let us consider only the X-dependence of air film i.e. $t \equiv t(x)$. The width 't(x)' of the air film inside the glass beam and the X-axis through the origin at a coordinate 'x' along X-axis can be obtained from

$$(R_x - t(x))^2 = R_x^2 - x^2 \quad \dots (2)$$

Assuming 't(x)' to be very small we can solve it to get

$$t(x) = \frac{x^2}{2R_x} \quad \dots (3)$$

Similarly, the width t(y) of the air film inside the glass beam and the XY-plane through the origin 'O' at a coordinate 'y' along Y-axis can be obtained from

$$t(y) = -\frac{y^2}{2R_y} \quad \dots (4)$$

It is to be noted that the sign is negative because along Y-axis the glass beams bends upward. Therefore, width of air film between parallel plate and glass beam at a coordinate (x, y) is given by

$$t(x, y) = t(x) + t(y) = \frac{x^2}{2R_x} - \frac{y^2}{2R_y} \quad \dots (5)$$

The shapes of the fringes are determined by the locus of all points that have identical path difference. In the present case, the path difference will be identical for points with a constant value of thickness 't(x,y)'. Thus the shape of the fringe will be given by

$$\frac{x^2}{2R_x} - \frac{y^2}{2R_y} = a^2 \quad \dots (6)$$

where 'a' is a constant and this is an equation of hyperbola. Therefore, the fringes will be hyperbolic.

It is important to note that the light waves passing through glass plate will be divided into two parts. One component would comprise the reflection from the bottom of the glass plate-air interface and the second one would be from the top of air film-glass beam interface. These two components would interfere and produce the fringe pattern. The latter one would undergo a phase change of π because of reflection at air film-glass beam interface. Also, this component traverses the width of the air film twice; therefore, the optical phase difference between these two waves (for almost normal incidence) is given by

$$\Delta\phi = \frac{2\pi}{\lambda} [2\mu t(x, y)] + \pi \quad \dots (7)$$

where ' μ ' is the refractive index of the film, λ is the free-space wavelength.

Let us consider the fringes along the X-axis and take into account that the air-film has a refractive index $\mu = 1$. If the distance of N-th dark fringe from the origin is x_N , then the interfering waves are essentially out-of-phase i.e.

$$\Delta\phi = (2N + 1)\pi \quad \dots (8)$$

$$2t_N(x) = \frac{x_N^2}{R_x} = N\lambda \quad \dots (9)$$

It is to be noted that in the case of grating this is precisely the condition for bright fringes. Therefore, if x_{N+s} is the distance of (N+s)-th dark fringe (along X-axis), we get

$$2t_{N+s}(x) = \frac{x_{N+s}^2}{R_x} = (N + s)\lambda \quad \dots (10)$$

Subtracting Eq. (9) from Eq. (10), we get

$$R_x = \frac{x_{N+x}^2 - x_N^2}{s\lambda} \quad \dots (11)$$

For convenience, we define

$$\rho_x(s) = x_{N+x}^2 - x_N^2 \quad \dots (12)$$

Thus, measuring the distance of different fringes from the origin, squaring them and subtracting we get the radius of curvature of the bent beam along X direction. Since, it is difficult to find the origin it is convenient to measure the ‘diameter’ (D) of the fringe, which is related by $D_{N_x} = 2x_N$ and is the distance between N-th dark fringe on left side of the origin and the N-th dark fringe on right side of the origin.

Once we obtain the radius of curvature along X-direction we can calculate the bending moment from it. This is given by the following relation

$$G_x = Y \cdot \frac{bd^3}{12} \frac{1}{R_x} \quad \dots (13)$$

where ‘b’ and ‘d’ are the width and thickness of the glass beam respectively while ‘Y’ is the Young’s modulus. The factors involving ‘b’ and ‘d’ comes from the moment of inertia of the glass beam about an axis which is at a distance of ‘ R_x ’ from the origin ‘O’ (see Figure 2) and parallel to Y-axis. This internal bending moment should be equal to the external bending moment applied by the loads hanging from the glass beam. If l is the distance between the knife-edge (the points where the glass beam is supported to the base) and the suspension point of the load W (= mg) then $G_x = W.l$ and therefore we can have

$$W.l = Y \cdot \frac{bd^3}{12} \frac{s\lambda}{\rho_x(s)} \quad \dots (14)$$

If we carry out the measurement for two different loads, then we obtain

$$(m_1 - m_2)gl = Y \frac{bd^3}{12} s\lambda \left(\frac{1}{\rho_x^1(s)} - \frac{1}{\rho_x^2(s)} \right) \quad \dots (15)$$

Equation (15) could be used for calculation of Young’s modulus.

In order to calculate the Poisson’s ratio, it is required to obtain the ratio of radius of curvature in the longitudinal direction to that in the transverse direction. In analogy with the argument leading to Eq. (11), we can obtain R_y by counting fringes along the Y-direction as,

$$R_y = \frac{y_{N+x}^2 - y_N^2}{s\lambda} \quad \dots (16)$$

where y_N is the distance of the N-th dark fringe from the center along Y-axis. Also, $\rho_y(s)$ is defined as

$$\rho_y(s) = y_{N+x}^2 - y_N^2$$

Therefore, Poisson's ratio is given by

$$\sigma = \frac{R_x}{R_y} = \frac{x_{N+x}^2 - x_N^2}{y_{N+x}^2 - y_N^2} \quad \dots (17)$$

3.5 PROCEDURE

1. Measure the width and the depth of the glass beam using vernier caliper and screw gauge. Take at least three readings for avoiding any error.
2. Place the glass beam on two knife-edges and hang the load (250 gm) on both sides. Measure the distance between knife-edge and point of suspension.
3. Place the plane glass plate on the glass beam near the middle. Adjust the glass beam and glass plate so that the fringes appear.
4. Focus the microscope and adjust the beam and plate so that the fringes are symmetrical on both sides of horizontal cross-wire and tangential to the vertical cross-wire.
5. Turning screw of the microscope measure longitudinal position (along X) of every transverse fringe on both sides. Take readings for about 10 fringes on both sides of the center. To avoid backlash error start from one extreme.
6. Similarly measure transverse position (along Y) of longitudinal fringes by moving microscope in transverse direction.
7. Increase the load to 300 grams and repeat the procedure from step 3.

3.6 OBSERVATION

$m_1 = 250$ grams

Along X

Order of the fringe	Fringes on the left (x)			Fringes on the right (x)			D (cm)	D ² (cm ²)	ρ_x (cm ²)	R _x
	Main Scale (cm)	Vernier scale	Total (cm)	Main Scale (cm)	Vernier scale	Total (cm)				

Along Y

Order of the fringe	Fringes on the left (y)			Fringes on the right (y)			D (cm)	D ² (cm ²)	ρ_y (cm ²)	R _y
	Main Scale (cm)	Vernier scale	Total (cm)	Main Scale (cm)	Vernier scale	Total (cm)				

3.7 CALCULATION

Do the correct error analysis and compare the result with the literature.

3.8 RESULT

Young’s modulus =

Poisson’s ratio =

3.9 PRECAUTIONS AND SOURCES OF ERROR

1. Handle the components carefully and make sure that the load > 400 grams is not exerted on the glass beam.

2. Make sure that you get regular shaped fringes. Adjust the glass plate slowly to change the shape of the fringes from any irregular pattern.
3. Be careful about the backlash error while taking the readings.

3.10 SUMMARY

An air film is obtained between convex lens and glass or Perspex beam. The light is made to fall normally on the air film with the help of a glass plate on the arrangement. The interference fringes formed is viewed by means of travelling microscope. Without adding any mass in the weight hanger we get circular rings. But as we uniformly add mass on the weight hangers the beam bends and we get elliptical fringes. During bending, an extension is caused on the upper surface and compression on the lower surface.

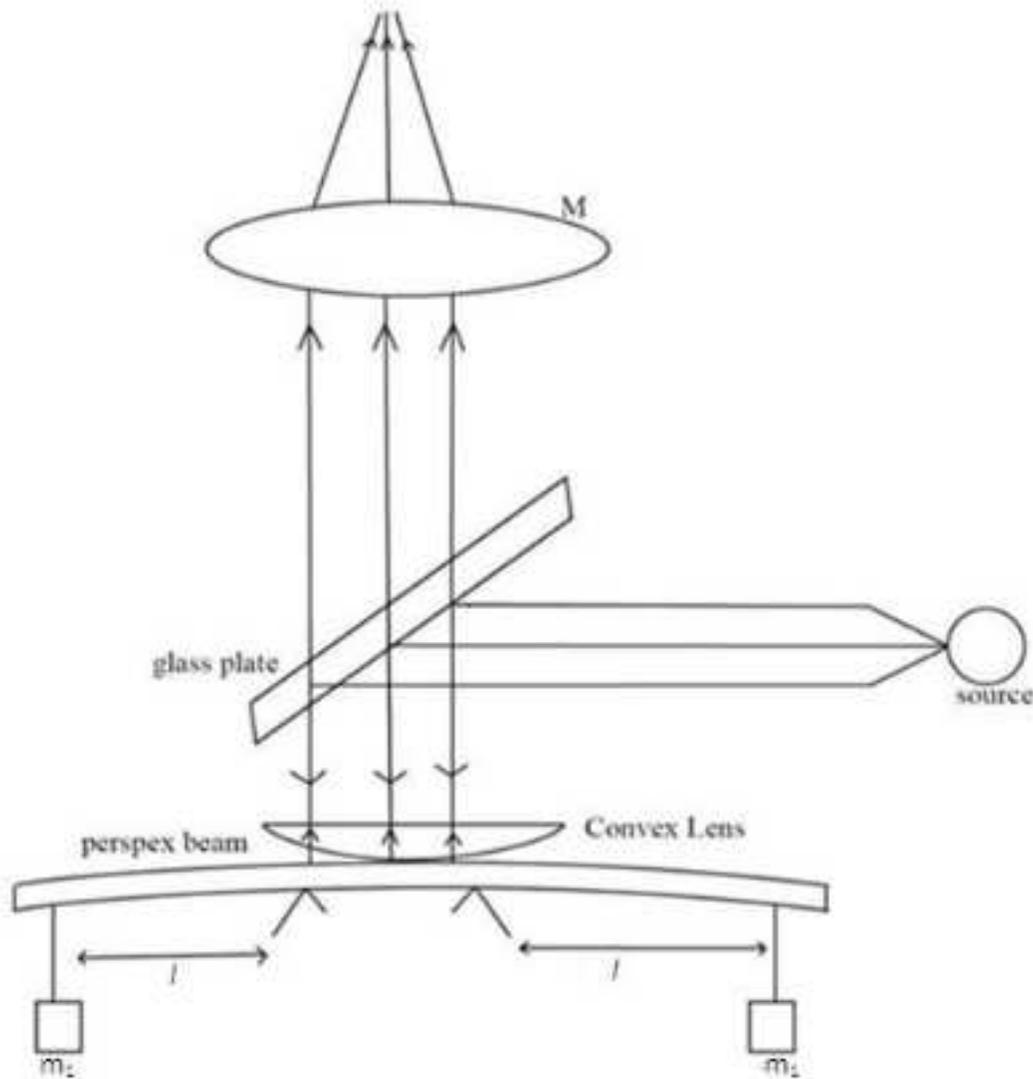


Figure 10: Cornus experimental setup.

Some of the points to discuss are as follows:

The diffraction pattern is observable even with naked eyes. If you observe the pattern formed on the air film at different angles in naked eye, you see that the pattern expands or contracts. This is because a thin film interference pattern you see depends on the angle at what you view the pattern.

The diffraction pattern blinks or sways slowly especially when the loads are disturbed. The changes are more prominently seen at the center of the diffraction pattern because the air film enclosed at the center is smaller and any change in the thickness of the air film due to the

disturbances account to a pretty large fraction of the thickness changing. For the same reason, as the thickness of the air film increases outwards from the center, any small change in the thickness due to disturbance won't be very observable. We can also observe that when we switch to the plano convex lens, the blinking dramatically is reduced in this scenario. This is because the convex lens and the glass slab now can enclose an air film of higher thickness in comparison to the glass slide and the glass slab.

The isotropicity of the glass material used could have been verified by using this experiment. If we were provided two glass slabs, where both the rectangular slabs were cut from the same glass slab but in two perpendicular directions, we could have done the experiment for both the slabs and compared the Young's modulus. However, we are checking for the isotropicity in only one direction. Perhaps, the experiment can be likewise extended from here.

For some material which has a smaller Young's modulus, we may use diffraction method to find the Poisson's ratio of such material. If we keep some material, say a rectangular bar of rubber in contact with some metal surface such that the rubber is in complete contact with the metal and light does not pass through in between them. We may stretch it now and shine a laser through the middle of the gap formed between the rubber and the metal to determine the change in the width of the rubber bar. And by measuring the change in length of the rubber bar using normal methods, we may calculate Poisson's ratio. We have to make an approximation that the slit formed is parallel.

More readings for this experiment can be gotten either by changing the weights that are being hanged or by changing the distance of the point of suspension from the knife edge as it is the torque which is producing the bend in the glass beam.

3.11 GLOSSARY

Fringe – a bright or dark band caused by beams of light that are in phase or out of phase with one another. Light waves and similar wave propagation, when superimposed, will add their crests if they meet in the same phase (the waves are both increasing, or both decreasing); or the troughs will cancel the crests if they are out of phase; these phenomena are called constructive and destructive interference, respectively. If a beam of monochromatic light (all waves having the same wavelength) is passed through two narrow slits (an experiment first performed in 1801 by Thomas Young, an English scientist, who inferred from the phenomenon the wavelike nature of light), the two resulting light beams can be directed to a flat screen on which, instead of forming two patches of overlapping light, they will form interference fringes, a pattern of evenly spaced alternating bright and dark bands. All optical interferometers function by virtue of the interference fringes that they produce.

Interference – In physics, interference is a phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude. Interference usually refers to the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency. Interference effects can be observed with all types of waves, for example, light, radio, acoustic, surface water waves or matter waves.

Poisson's Ratio - Poisson's ratio is a measure of the Poisson effect, the phenomenon in which a material tends to expand in directions perpendicular to the direction of compression. Conversely, if the material is stretched rather than compressed, it usually tends to contract in the directions transverse to the direction of stretching.

Young's Modulus – Young's modulus is a measure of the ability of a material to withstand changes in length when under lengthwise tension or compression. Sometimes referred to as the modulus of elasticity, Young's modulus is equal to the longitudinal stress divided by the strain.

3.12 REFERENCES

1. Mechanical Engineering Information, www.roymech.co.uk
2. N. K. Mehta, Machine Tool Design and Numerical Control, McGraw-Hill Publishing, pp173
3. Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light (7th Edition), Max Born Emil Wolf

3.13 VIVA-VOCE QUESTIONS AND ANSWERS

1) Which among the following is not regarded as an elastic constant of a material?

- | | |
|---------------------|--------------------|
| A. Rigidity Modulus | B. Young's Modulus |
| C. Refractive index | D. Poisson's Ratio |

Ans: C

2) Young's Modulus has:

- | | |
|---------------------|------------------|
| A. Unit of Force | B. No Unit |
| C. Unit of Pressure | D. None of these |

Ans: C

3) If we stretch a wire, the amount it stretches depends upon?

- A. The material it is made of B. Length
C. Diameter D. All the above

Ans: D

4) The coefficient of elasticity for a shearing force is known as?

- A. Rigidity Modulus B. Young's Modulus
C. Poisson's Ratio D. None of these

Ans: A

5) What is the unit of transverse to longitudinal strain of a loaded specimen?

- A. No unit B. Nm^{-2}
C. Pascal D. None of these

Ans: A

6) What does a high Young's modulus mean?

Young's modulus measures the resistance of a material to elastic (recoverable) deformation under load. A stiff material has a high Young's modulus and changes its shape only slightly under elastic loads (e.g. diamond). A flexible material has a low Young's modulus and changes its shape considerably (e.g. rubbers).

7) Can you change the Young's modulus?

Young's Modulus of a material is a fundamental property of every material that cannot be changed. It is dependent upon temperature and pressure however.

When a material has reached a certain stress, the material will begin to deform. It is up to this point where the materials structure is stretching and not deforming. However, if you are to stress the material more than this, the molecules or atoms inside will begin to deform and permanently change the material. A good analogy to this would be a rubber band: when you stretch a rubber band you are not deforming it, but stretching it. However, if you pull it too hard the rubber band will begin to deteriorate, or deform. Usually when this happens, it is not too much longer until it breaks.

Experiment 4:

STUDY OF B-H CURVE

Structure

4.1 Object

4.2 Introduction

4.3 Apparatus

4.4 Theory and Formula Used

4.5 Procedure

4.6 Observation

4.7 Calculation

4.8 Result

4.9 Precautions and Sources of Error

4.10 Summary

4.11 Glossary

4.12 References

4.13 Viva-voce Questions and Answers

4.1 OBJECT

To determine the ferromagnetic constants: retentivity, permeability and susceptibility by tracing the B-H curve.

4.2 INTRODUCTION

Consider a magnetic material being subjected to a cycle of magnetization. The graph intensity of magnetization (B) vs. magnetizing field (H) gives a closed curve called B-H loop. Consider the portion AB of the curve given below. The intensity of magnetization B does not become zero when the magnetizing field H is reduced to zero. Thus the intensity of magnetization B at every stage lags behind the applied field H. This property is called magnetic hysteresis. The B-H loop is called hysteresis loop. The shape and area of the loop are different for different materials.

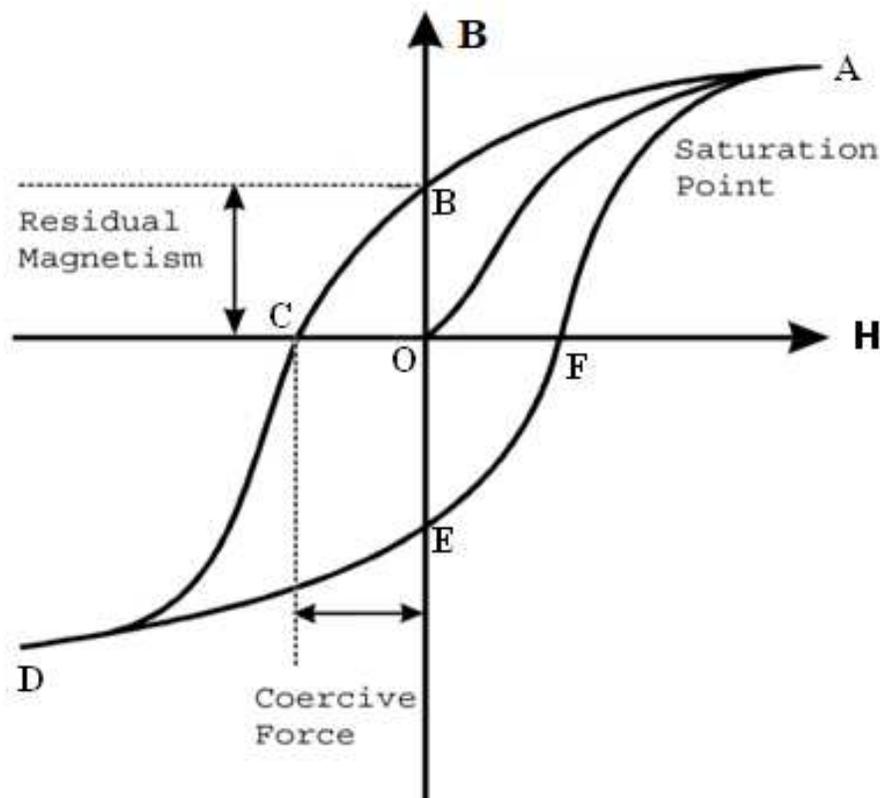


Figure 11: Magnetic hysteresis loop showing coercive force OC, residual magnetism OB, saturation point A.

Hysteresis Loop

An initially unmagnetized material is subjected to a cycle of magnetization. The values of intensity of magnetization B and the magnetizing field H are calculated at every stage and a closed loop is obtained on plotting a graph between B and H as shown in the figure. The point

'O' represents the initial unmagnetized condition of the material. As the applied field is increased, the magnetization increases to the saturation point 'A' along 'OA'. As the applied field is reduced, the loop follows the path 'AB'. 'OB' represents the intensity of magnetization remaining in the material when the applied field is reduced to zero. This is called the residual magnetism. The property of retaining some magnetism on removing the magnetic field is called retentivity. OC represents the magnetizing field to be applied in the opposite direction to remove residual magnetism. This is called coercive field and the property is called coercivity. When the field is further increased in the reverse direction the material reaches negative saturation point 'D'. When the field is increased in positive direction, the curve follows path 'DEF'.

4.3 APPARATUS

The apparatus consists of electronic training board New Tech Type NTI – 226. It consists of a solenoid having primary and secondary coils, specimen in the form of several thin wires of iron grouped to form a rod. The training board consists of one AC milliammeter and one AC voltmeter. In addition to the apparatus, one CRO is required to perform the experiment.

4.4 THEORY AND FORMULA USED

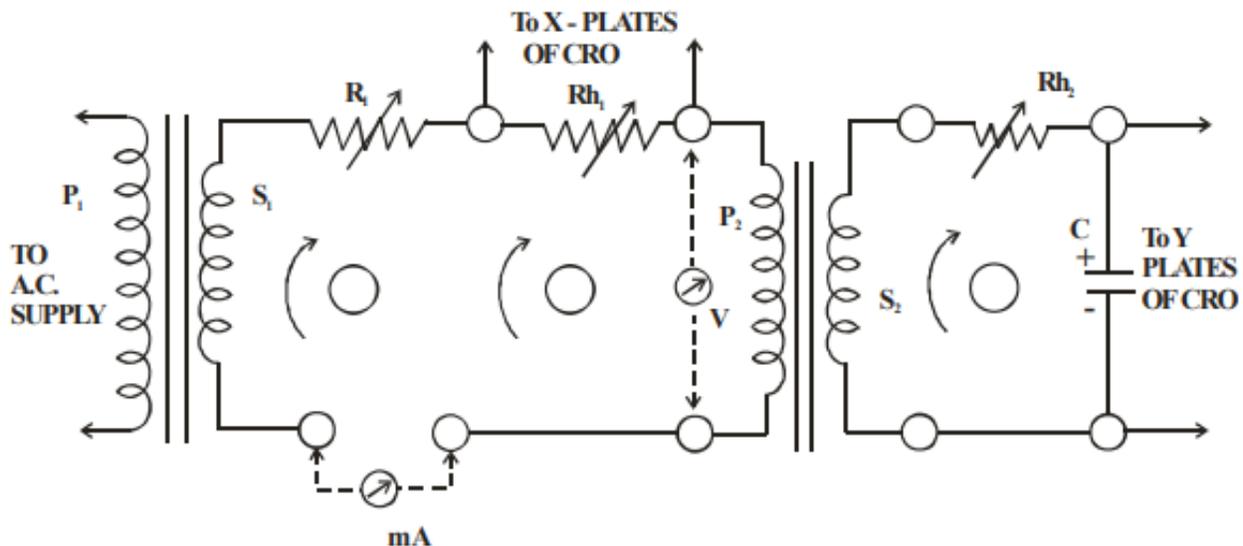


Figure 12: Circuit Diagram for obtaining B-H curve on CRO screen.

The specimen is put inside the solenoid and is subjected to a varying magnetic field H. In this experiment magnetic field H is produced by passing A.C. current in the solenoid is given by –

$$H = \frac{4 \pi n \sqrt{2} I_{rms}}{10} \cos \omega t \quad (1)$$

where I_{rms} is the current in ampere measured by the ammeter and n is the number of turns per cm in the primary coil of the solenoid. The potential difference developed across R_{h1} is fed to xx plates of CRO and consequently, x deflection will be proportional to H . Its maximum value is:

$$H_{max} = \frac{4 \pi n \sqrt{2} I_{rms}}{10}$$

Trace length L_x corresponds to $2H_{max}$ (Figure 3).

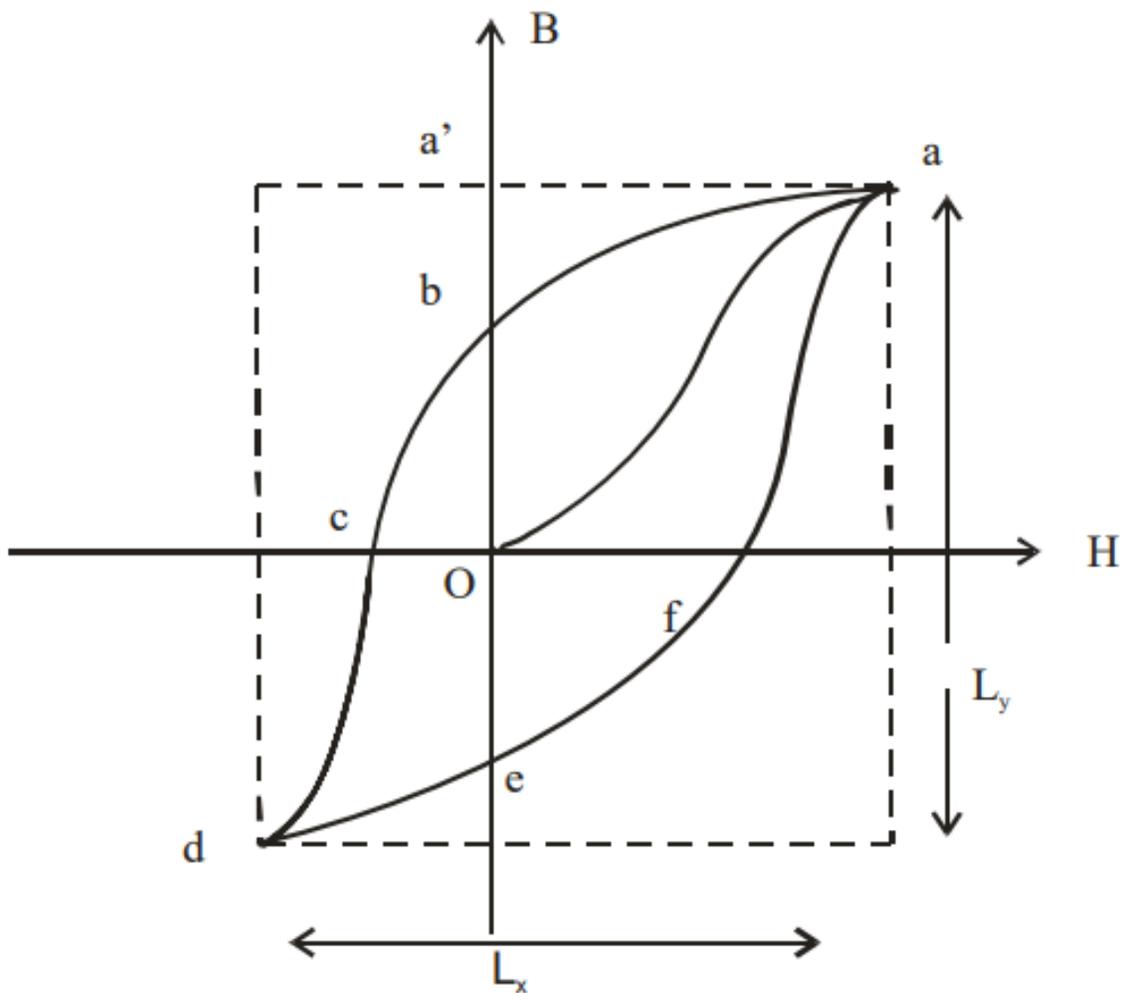


Figure 13: B-H Curve tracing taken on tracing paper.

Hence, the calibration constant for H axis is:

$$C_x = \frac{2H_{\max}}{L_x} \dots\dots\dots (1)$$

$$\text{Where } H_{\max} = \frac{4 \pi n \sqrt{2} I_{\text{rms}}}{10} \text{ Oersted} \dots\dots\dots (2)$$

Calibration constant for B axis is:

$$C_y = \frac{2H_{\max} \cdot F}{L_y} \text{ Gauss / cm.} \dots\dots\dots (3)$$

$$\therefore 2(\Phi_{\text{air}})_{\max} = 2H_{\max} S$$

where S is area of Cross section of primary coil and F is amplification factor of y amplifier, and

$$B = \frac{\Phi_{\max}}{S}$$

Retentivity corresponding to Y

If Ob = cm on the trace

$$\therefore \text{Retentivity} = \text{Ob} \times C_y = \dots\dots\dots \text{ Gauss} \dots\dots\dots (4)$$

Saturation corresponding to Y

If Oa' = ----- as on the trace

$$\therefore B_{\max} = \text{Oa}' \times C_y \dots\dots\dots (5)$$

Coercivity:

If OC = cm on the trace

$$\therefore \text{Coercivity} = \text{OC} \times C_x \dots\dots\dots (6)$$

Hysteresis loss per cycle per unit Volume

$$\begin{aligned}
 &= (1/4\pi) \text{ (Area of B-H curve)} \\
 &= (1/4\pi) \text{ (Area of B-H curve on the trace)} C_x.C_y \\
 &= (1/4\pi) . A . C_x . C_y \dots\dots\dots (7) \\
 &= \dots\dots\dots \text{ ergs per cycle per cm}^3
 \end{aligned}$$

Permeability:

$$\begin{aligned}
 \mu &= B/H \text{ or } B_{\max} / H_{\max} \dots\dots\dots (8) \\
 &= \dots\dots\dots
 \end{aligned}$$

Susceptibility:

$$\begin{aligned}
 \therefore \mu &= 1 + 4\pi X_m \\
 \therefore X_m &= (\mu - 1) / 4\pi \dots\dots\dots (9) \\
 &= \dots\dots\dots
 \end{aligned}$$

4.5 PROCEDURE

1. Make the connections as shown in Figure 5.
2. By adjusting R_{h1} , R_{h2} and amplifiers of CRO obtain a B-H loop of suitable size on the screen of CRO.
3. By varying R_{h1} , values of V and I can be changed.
4. Take a trace of B-H curve on tracing paper.

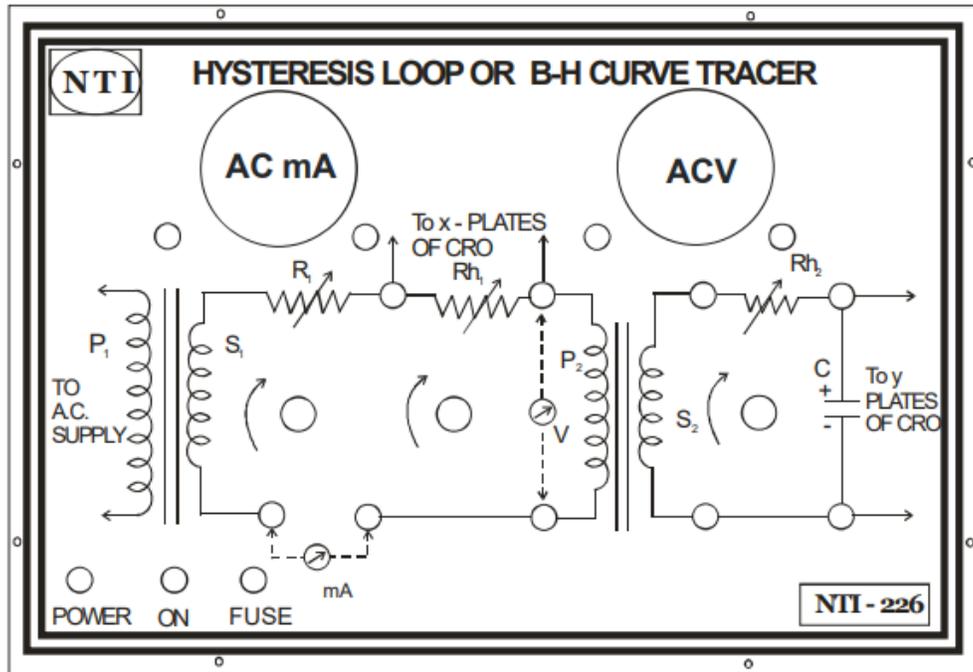


Figure 14: Panel diagram.

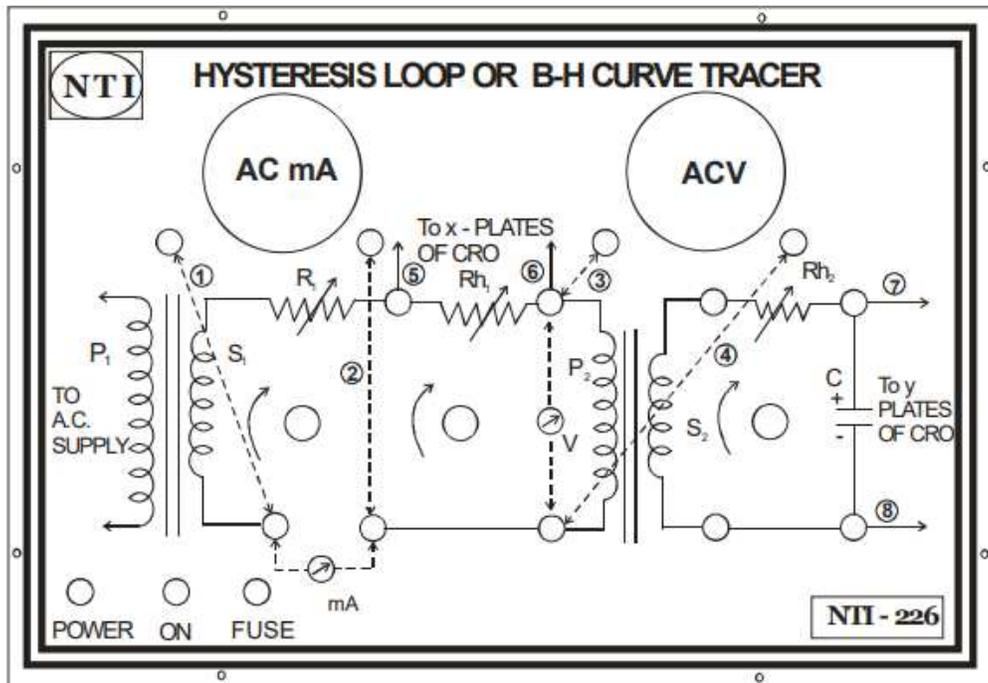


Figure 15: Connections for Hysteresis Loop or B-H Curve Tracer.

4.6 OBSERVATION**(i) Table 1**

n = 3000 turns/cm

S. No.	Current (I) amp	Potential Difference (V) volt	Area of loop (cm ²)
1.			
2.			
3.			
4.			
5.			

4.7 CALCULATION

From the trace of B-H loop on tracing paper measure different lengths i.e. Ob, Oa', OC etc. and calculate the values of Retentivity, Saturation, Coercivity, Permeability, Susceptibility and Hysteresis loss using the appropriate formula mentioned in the theory.

4.8 RESULT

The magnetic constants for iron are:

1. Retentivity = Gauss

2. Coercivity = Oersted

3. Hysteresis loss per cycle per unit volume = ergs / cycle / cm³

4. Permeability =

5. Susceptibility =

4.9 PRECAUTIONS AND SOURCES OF ERROR

1. The current in the primary of solenoid should be quite large so as to magnetize the specimen sufficiently.
2. Handle CRO carefully.
3. Trace of B-H curve should be taken as tracing paper and it should be of suitable size.

4.10 SUMMARY

The quantities now used in characterizing magnetization were defined and named by William Thomson (Lord Kelvin) in 1850. The symbol B denotes the magnitude of magnetic flux density inside a magnetized body, and the symbol H denotes the magnitude of magnetizing force, or magnetic field, producing it. The two are represented by the equation $B = \mu H$, in which the Greek letter mu, μ , symbolizes the permeability of the material and is a measure of the intensity of magnetization that can be produced in it by a given magnetic field. The modern units of the International Standard (SI) system for B are teslas (T) or webers per square metre (Wb/m^2) and for H are amperes per metre (A/m). The units were formerly called, respectively, gauss and oersted. The units of μ are henrys per metre.

All ferromagnetic materials exhibit the phenomenon of hysteresis, a lag in response to changing forces based on energy losses resulting from internal friction. If B is measured for various values of H and the results are plotted in graphic form, the result is a loop called a hysteresis loop. The name describes the situation in which the path followed by the values of B while H is increasing differs from that followed as H is decreasing. With the aid of this diagram, the characteristics needed to describe the performance of a material to be used as a magnet can be defined. B_s is the saturation flux density and is a measure of how strongly the material can be magnetized. B_r is the remanent flux density and is the residual, permanent magnetization left after the magnetizing field is removed; this latter is obviously a measure of quality for a permanent magnet. It is usually measured in webers per square metre. In order to demagnetize the specimen from its remanent state, it is necessary to apply a reversed magnetizing field, opposing the magnetization in the specimen. The magnitude of field necessary to reduce the magnetization to zero is H_c , the coercive force, measured in amperes per metre. For a permanent magnet to retain its magnetization without loss over a long period of time, H_c should be as large as possible. The combination of large B_r and large H_c will generally be found in a material with a large saturation flux density that requires a large field to magnetize it. Thus, permanent-magnet materials are often characterized by quoting the maximum value of the product of B and H , $(BH)_{\text{max}}$, which

the material can achieve. This product $(BH)_{\max}$ is a measure of the minimum volume of permanent-magnet material required to produce a required flux density in a given gap and is sometimes referred to as the energy product.

4.11 GLOSSARY

Coercivity – In electrical engineering and materials science, the coercivity, also called the magnetic coercivity, coercive field or coercive force, is a measure of the ability of a ferromagnetic material to withstand an external magnetic field without becoming demagnetized. An analogous property, electric coercivity, is the ability of a ferroelectric material to withstand an external electric field without becoming depolarized.

For ferromagnetic material the coercivity is the intensity of the applied magnetic field required to reduce the magnetization of that material to zero after the magnetization of the sample has been driven to saturation. Thus coercivity measures the resistance of a ferromagnetic material to becoming demagnetized. Coercivity is usually measured in oersted or ampere/meter units. It can be measured using a B-H analyzer or magnetometer.

Hysteresis – lagging of the magnetization of a ferromagnetic material, such as iron, behind variations of the magnetizing field. When ferromagnetic materials are placed within a coil of wire carrying an electric current, the magnetizing field, or magnetic field strength H , caused by the current forces some or all of the atomic magnets in the material to align with the field. The net effect of this alignment is to increase the total magnetic field, or magnetic flux density B . The aligning process does not occur simultaneously or in step with the magnetizing field but lags behind it.

Magnetization – Magnetization is the density of magnetic dipole moments that are induced in a magnetic material when it is placed near a magnet. The magnetic effects of a material can also be induced by passing an electrical current through the material; the magnetic effect is caused by the motion of electrons in atoms, or the spin of the electrons or the nuclei.

Magnetization is also known as magnet polarization.

Permeability – In electromagnetism, permeability is the measure of the ability of a material to support the formation of a magnetic field within itself otherwise known as the distributed inductance of the vacuum. Hence, it is the degree of magnetization that a material obtains in response to an applied magnetic field. Magnetic permeability is typically represented by the (italicized) Greek letter μ . The term was coined in September 1885 by Oliver Heaviside.

Retentivity – the ability of a substance to retain or resist magnetization, frequently measured as the strength of the magnetic field that remains in a sample after removal of an inducing field.

Iron is easily magnetized but has low retentivity.

Susceptibility – In electromagnetism, the magnetic susceptibility is one measure of the magnetic properties of a material. The susceptibility indicates whether a material is attracted into or repelled out of a magnetic field, which in turn has implications for practical applications. Quantitative measures of the magnetic susceptibility also provide insights into the structure of materials, providing insight into bonding and energy levels.

If the magnetic susceptibility is greater than zero, the substance is said to be "paramagnetic"; the magnetization of the substance is higher than that of empty space. If the magnetic susceptibility is less than zero, the substance is "diamagnetic"; it tends to exclude a magnetic field from its interior.

4.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017
2. University Practical Physics, D. C. Tayal – Himalaya Publishing House, Mumbai, 2000

4.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. What do you understand by residual flux density?

Ans: Residual flux density is a magnetic flux density remaining in material when the magnetic field strength is decreased to zero after being magnetized to its saturation point.

2. What is a hysteresis loop?

Ans: Hysteresis loop is a closed curve showing the variation of the magnetic flux density of a ferromagnetic material with the external magnetic field producing it, when this field is changed through a complete cycle.

3. Why is soft iron used in transformer cores and electric motors?

Ans: Magnetically soft (low coercivity) iron is used for the cores in electromagnets. The lower magnetic coercivity reduces the energy loss associated with hysteresis. The low energy loss during a hysteresis loop is also the reason why soft iron is used for transformer cores and electric motors.

4. It is easier to demagnetize soft iron than steel. Explain.

Ans. The area under hysteresis curve for soft iron is small whereas the area under hysteresis curve for steel is large. Larger the area under hysteresis curve, more difficult is it to demagnetize. So, due to the small area under the hysteresis curve for soft iron, it is easier to demagnetize it.

5. A bar magnet of iron is heated to 1000°C . Does it retain its magnetism on cooling?

Ans. The Curie temperature of iron is 750°C , and above this temperature, iron loses its ferromagnetic property and turns into a paramagnetic material. When it is cooled down, it is unable to retain its magnetism itself.

6. Distinguish between Ferromagnetic, Paramagnetic and Diamagnetic substances based on permeability and susceptibility.

Ans:

Permeability	Very high	A little more than unity.	A little less than unity.
Susceptibility	Very high and positive.	A little more than unity and positive.	A little less than unity and negative.

Experiment 5:

VERIFICATION OF HARTMANN'S FORMULA

Structure

5.1 Object

5.2 Introduction

5.3 Apparatus

5.4 Theory and Formula Used

5.5 Procedure

5.6 Observation

5.7 Calculation

5.8 Result

5.9 Precautions and Sources of Error

5.10 Summary

5.11 Glossary

5.12 References

5.13 Viva-voce Questions and Answers

5.1 OBJECT

To verify Hartmann's dispersion formula using a constant deviation spectrometer.

5.2 INTRODUCTION

Hartmann's dispersion formula is a semi-empirical formula relating the index of refraction n and wavelengths λ . It is also referred to as Cornu-Hartmann formula.

5.3 APPARATUS

Constant deviation spectrometer, mercury lamp, sodium lamp, reading lamp and reading lens.

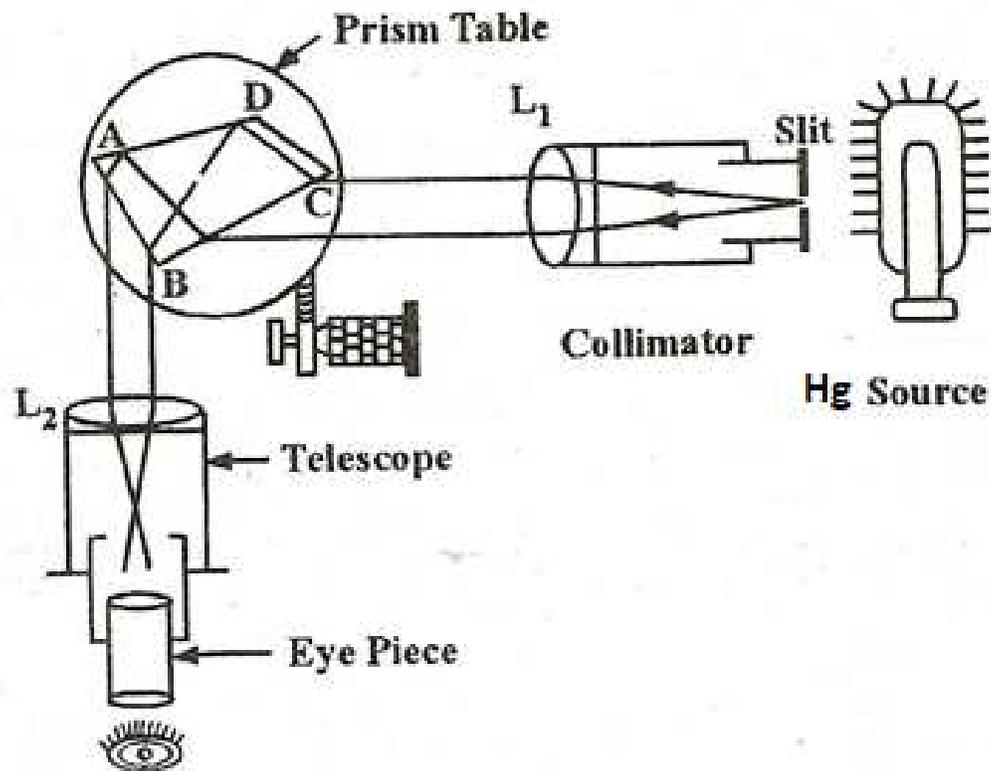


Figure 1: Constant Deviation Spectrometer

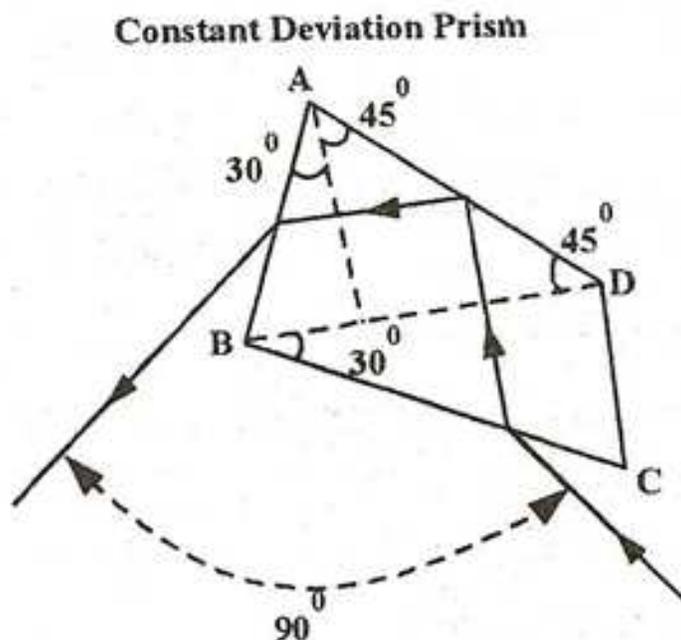


Figure 2: Constant Deviation Prism.

5.4 THEORY AND FORMULA USED

Hartmann suggested an equation for the wavelength of the spectral line which is at a distance x from a fixed mark in the spectrum and is known as Hartmann's dispersion formula.

It is given by

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

where A , B and C are constants.

5.5 PROCEDURE

5. Place the sodium lamp before the collimator. Open the slit widely and see it through the telescope tube (without eye piece).
6. Adjust the position and height of the lamp to get the image in the center of the prism face.
7. Remove the dust particles if any and narrow the slit to have a fine pencil of rays.
8. Set the wavelength drum at 5890 \AA (D_1 or D_2 marked on the drum). Focus the eye piece. If the image of the spectral line viewed in the eye piece is far removed from the center of the field of view of the eye piece, the constant deviation prism requires setting. If the image of the spectral line is near the center, do not move the prism. A minor adjustment

by means of screws provided with the eye piece is sufficient. The spectrometer is now set up.

9. Replace the sodium lamp by the mercury lamp, which provides a number of lines of accurately known wavelengths in the visible spectrum. Note these wavelengths from the standard tables.
10. Rotate the wavelength drum to bring the spectral lines in turn to coincide with the cross-wire or the pointer in the field of view of the eye piece. Read and record the wavelengths of the visible spectral lines on the drum. Now compare these wavelengths with the standard wavelengths noted from the table.
11. With the help of the drum, adjust the spectrum in the field of view (if whole of the spectrum does not come in the field of view, divide it into two parts). Note down the position of the lines on the micrometer scale attached with the eye piece.

5.6 OBSERVATION

Table for the measurement of wavelength of spectral lines and their positions

Wavelength of spectral lines	Positions of spectral lines
$\lambda_1 =$	$x_1 =$
$\lambda_2 =$	$x_2 =$
$\lambda_3 =$	$x_3 =$

5.7 CALCULATION

Consider three conveniently spaced lines of known wavelengths λ_1 , λ_2 and λ_3 . Their positions x_1 , x_2 and x_3 are noted on the micrometer scale attached with the eye piece (or a travelling microscope).

Using the relation

$$\lambda_1 = A + \frac{B}{x_1 - C}$$

$$\lambda_2 = A + \frac{B}{x_2 - C}$$

$$\lambda_3 = A + \frac{B}{x_2 - C}$$

A, B and C are calculated.

Now using the values of A, B and C, the wavelengths of other spectral lines are calculated with the Hartmann's dispersion formula by substituting the observed values of x for these lines.

5.8 RESULT

The wavelengths so obtained are compared with the drum's readings and the values given in the standard tables. Since, the values are very close to the required or expected values, hence the Hartmann's formula is verified.

5.9 PRECAUTIONS AND SOURCES OF ERROR

1. The mechanical and optical adjustments of the telescope must be made carefully and correctly.
2. While taking observations, the prism table and telescope must keep clamped.
3. The prism should be placed properly and correctly on the prism table.
4. Telescope should be rotated in the same direction.
5. While taking observations, the prism table and the telescope should never be unclamped together.

5.10 SUMMARY

A simple interpolation formula for the prismatic spectrum was proposed by J. Hartmann in Astrophysical Journal, vol. 8, p.218. In this experiment, we compare the wavelengths obtained with the drum's readings and the values given in the standard tables. Because, the values are very close to the required or expected values, the Hartmann's formula is deemed to be true.

5.11 GLOSSARY

Collimator – A collimator is a device that narrows a beam of particles or waves. To narrow can mean either to cause the directions of motion to become more aligned in a specific direction (i.e., make collimated light or parallel rays), or to cause the spatial cross section of the beam to become smaller (beam limiting device).

Dispersion – the separation of white light into colors or of any radiation according to wavelength.

Prism – Prisms can be made from any material that is transparent to the wavelengths for which they are designed. Typical materials include glass, plastic, and fluorite. A dispersive prism can be used to break light up into its constituent spectral colors (the colors of the rainbow).

Refraction – Refraction is the change in direction of wave propagation due to a change in its transmission medium. The phenomenon is explained by the conservation of energy and the conservation of momentum.

Refractive Index – In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how light propagates through that medium.

Semi-empirical – partly empirical; especially involving assumptions, approximations, or generalizations designed to simplify calculation or to yield a result in accord with observation.

Spectral Line – A spectral line is a dark or bright line in an otherwise uniform and continuous spectrum, resulting from emission or absorption of light in a narrow frequency range, compared with the nearby frequencies. Spectral lines are often used to identify atoms and molecules.

Spectrometer – an apparatus used for recording and measuring spectra, especially as a method of analysis.

Spectrum – Spectrum, in optics, the arrangement according to wavelength of visible, ultraviolet, and infrared light. An instrument designed for visual observation of spectra is called a spectroscope; an instrument that photographs or maps spectra is a spectrograph.

Wavelength – the distance between successive crests of a wave, especially points in a sound wave or electromagnetic wave.

5.12 REFERENCES

1. Introduction to Physics, Cutnell, Johnson, Young, Stadler – Wiley India, 2017
2. University Practical Physics, D. C. Tayal – Himalaya Publishing House, 2000

5.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. Can we identify each element with a constant deviation spectrometer?

Ans: An unknown element can be identified with its characteristic spectral lines.

2. What is the use of a spectrometer and what are its main components?

Ans: The spectrometer is an instrument used to obtain a pure spectrum. It has three components:

- (a) Collimator
- (b) Telescope
- (c) Prism Table

3. What is a travelling microscope?

Ans: A travelling microscope is an instrument for measuring length with a resolution typically in the order of 0.01mm. The precision is such that better-quality instruments have measuring scales made from Invar to avoid misreading due to thermal effects. The instrument comprises a microscope mounted on two rails fixed to, or part of a very rigid bed. The position of the microscope can be varied coarsely by sliding along the rails, or finely by turning a screw. The eyepiece is fitted with fine cross-hairs to fix a precise position, which is then read off the Vernier scale.

4. How are spectra classified?

Ans: Spectra may be classified according to the nature of their origin, i.e., emission or absorption.

An emission spectrum consists of all the radiations emitted by atoms or molecules, whereas in an absorption spectrum, portions of a continuous spectrum (light containing all wavelengths) are missing because they have been absorbed by the medium through which the light has passed; the missing wavelengths appear as dark lines or gaps.

The spectrum of incandescent solids is said to be continuous because all wavelengths are present. The spectrum of incandescent gases, on the other hand, is called a line spectrum because only a few wavelengths are emitted. These wavelengths appear to be a series of parallel lines because a slit is used as the light-imaging device. Line spectra are characteristic of the elements that emit the radiation. Line spectra are also called atomic spectra because the lines represent wavelengths radiated from atoms when electrons change from one energy level to another. Band spectra is the name given to groups of lines so closely spaced that each group appears to be a band, e.g., nitrogen spectrum. Band spectra, or molecular spectra, are produced by molecules radiating their rotational or vibrational energies, or both simultaneously.

Experiment 6:

FRANCK-HERTZ EXPERIMENT

Structure

6.1 Object

6.2 Introduction

6.3 Apparatus

6.4 Theory and Formula Used

6.5 Procedure

6.6 Observation

6.7 Calculation

6.8 Result

6.9 Precautions and Sources of Error

6.10 Summary

6.11 Glossary

6.12 References

6.13 Viva-voce Questions and Answers

6.1 OBJECT

Study of quantized excitation of Neon atoms by inelastic scattering and determine the excitation energy.

6.2 INTRODUCTION

Franck and Hertz described the first observation of quantized excitation in 1914; one year after Bohr published his theory of the hydrogen atom with its concept of quantized energy states. They discovered that electrons moving through the mercury vapor with energy equal to or greater than a certain critical value (4.9eV) can excite the 253.6 nm line of mercury. Electrons with less than the critical merely bounce off elastically when they collide with mercury atom and fail to excite any electromagnetic radiation at all.

This experiment provided crucial evidence in favor of Bohr Theory. In this experiment excitation of Ne atoms is studied by inelastic collision with electrons. The electrons emitted from the indirectly heated cathode of a tetrode filled with neon vapors are accelerated. The excited atoms emit visible light that can be viewed directly. The excitation energy of neon is determined from the distance between the equidistant maxima of the electron current in variable opposing electric field.

6.3 APPARATUS

The set up uses a tetrode as a Franck-Hertz tube. It has an indirectly heated barium oxide cathode (C), two mesh-type grids (control grid S and anode grid G) and an anode (A) as shown in Figure 1.

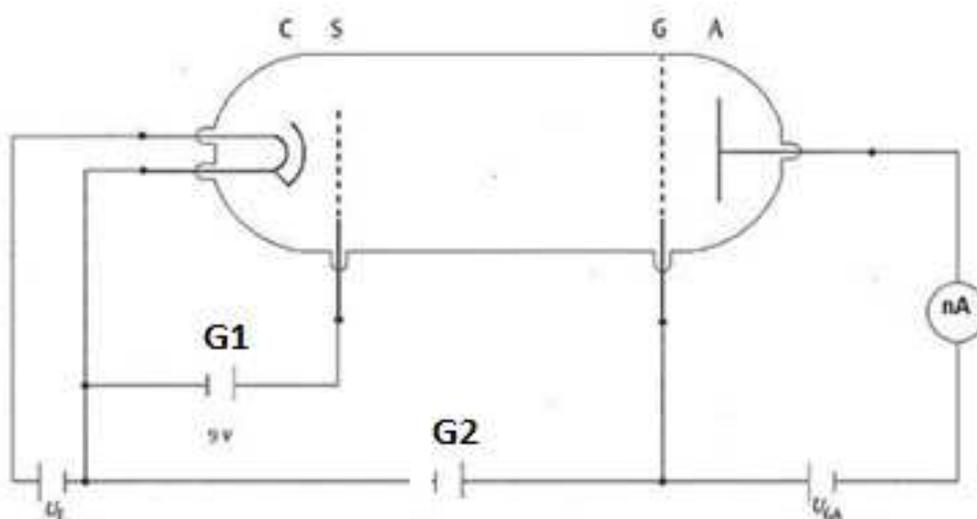


Figure 1: Franck-Hertz tube filled with Ne (C: cathode, S: control grid, G: anode grid, A: anode).

The electrodes are in a plane-parallel configuration. The distance between the control grid and the anode grid is about 5 mm, and the distances between the cathode and the control grid and between the anode grid and anode are about 2 mm each. The tube is filled with neon gas at a pressure chosen to give an optimum characteristic curve, which is in the region of several hundred Pascal.

6.4 THEORY AND FORMULA USED

Neon atoms are excited by inelastic collision with electrons emitted by the cathode in a Frank-Hertz tube. The cathode in the tube is heated by a filament to emit electrons in a process called thermionic emission. After absorbing energy from collisions, electrons in Ne atoms are excited and subsequently de-excited to produce a visible glow in the gas that can be viewed directly. The energy level diagram for Ne is shown in Figure 2. The most probable excitation through inelastic electron collision takes place from the ground state to the ten 3p-states, which are between 18.4 eV and 19.0 eV above the ground state. The four lower 3s-states in the range from 16.6 eV and 16.9 eV are excited with a lower probability. The de-excitation of the 3p-states to the ground is only possible via the 3s-states. The 3p-3s transition leads to emission of a photon. The light emitted in this process lies in the visible range between red and green, and can thus be observed with the naked eye.

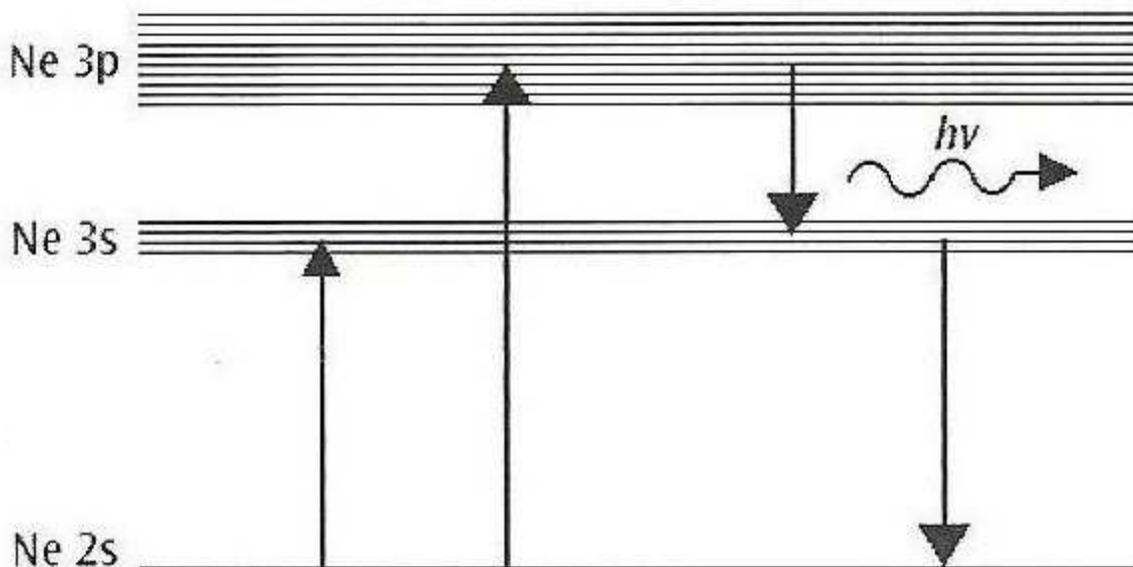


Figure 2: Energy level diagram for Ne

In the Franck-Hertz tube, electrons are emitted from the cathode and form a charge cloud. These electrons are accelerated by the driving potential $G1$ between the cathode and control grid S . A braking voltage UGA is present between G and anode A . Only electrons with sufficient kinetic

energy can reach the anode and contribute to the collector current. A typical plate current versus accelerating voltage characteristics is shown in Figure 3.

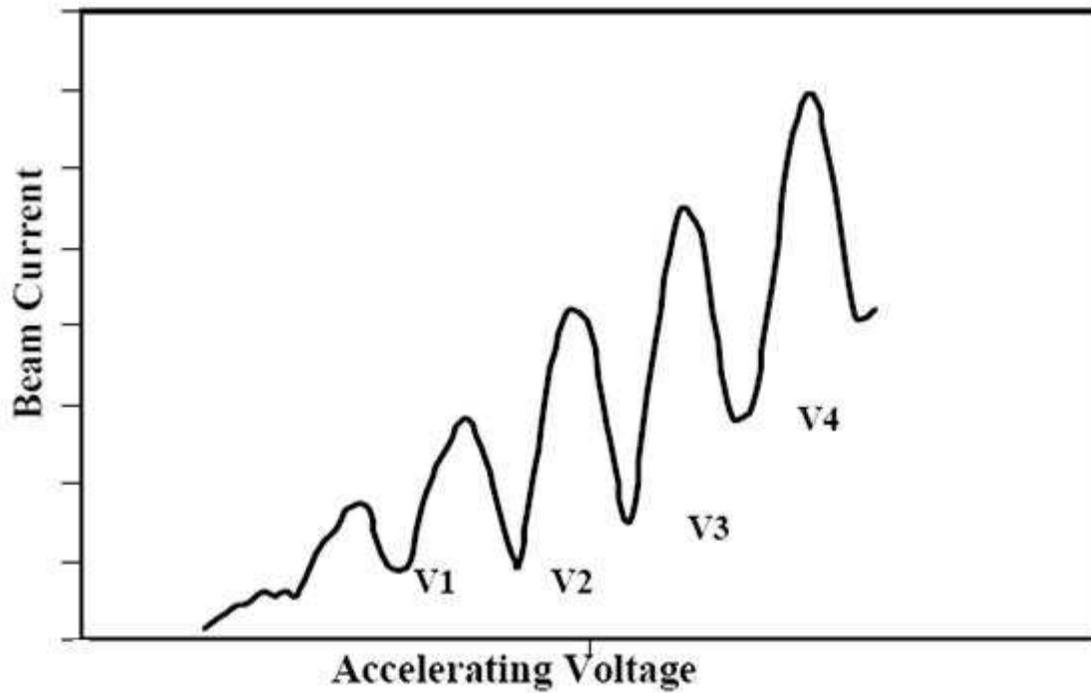


Figure 3: Typical Franck-Hertz curve showing plate current versus accelerating voltage characteristics

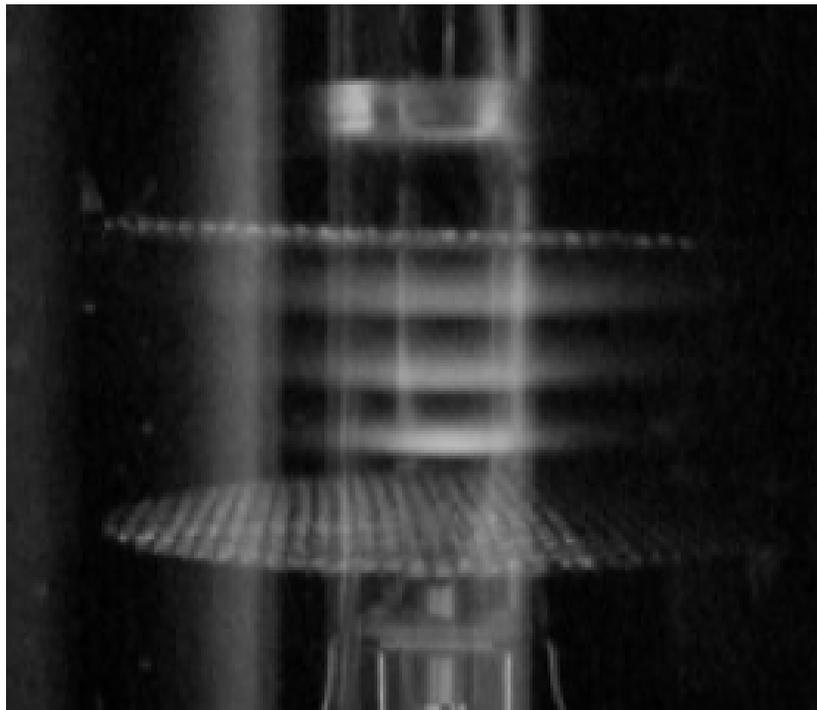


Figure 4: Visible luminescence layers between grids

As the acceleration voltage G_2 is increased while U_F , G_1 and U_{GA} are held constant, the corresponding collector current initially increases, It reaches a maximum when the kinetic energy of the electrons closely in front of grid G_2 is just sufficient to transfer the energy required to excite the neon atoms through collisions. The collector current drops off dramatically, as after collision the electrons can no longer overcome the braking voltage U_{GA} . As the acceleration voltage U_2 increases, the electrons attain the energy level required for exciting the neon atoms at ever greater distances from grid G_2 . After collision, they are accelerated once more and when the acceleration voltage is sufficient, again they absorb so much energy from the electric field that they can excite a neon atom. The result is a second maximum, and at greater voltages U_2 further maxima of the collector currents are observed. At higher acceleration voltages, we can observe discrete red luminance layers between grids G_1 and G_2 as shown in Figure 4.

Franck and Hertz used their data to measure the threshold voltage V at which the photons appeared and then derived the value for the Planck's constant

$$\frac{h}{2\pi} = \left(\frac{eV}{c}\right)\lambda$$

which agreed with the values previously obtained by Planck, Einstein and Bohr from Blackbody radiations, Photoelectric effect and Hydrogen spectrum, respectively. This was a striking confirmation of new quantum theory.

6.5 PROCEDURE

12. The Neon tube unit is mounted on the 4 mm socket provided on the top of the Franck-Hertz base unit as shown in Figure 5.
13. Put the toggle switch in the manual mode.
14. Set all the control knobs at extreme anti-clockwise position of the Franck-Hertz base unit.
15. Connect the Franck-Hertz base unit plug to mains and switch ON the unit.
16. Now set the filament voltage U_F at 8.2 – 8.5 Vm approximately and wait for 3 – 5 minutes.
17. Set G_1 at 6 - 8V and U_{GA} at 7 - 9V approximately.
18. Set the GAIN knob at maximum position (extreme clockwise direction) and adjust the plate (anode) current to zero using OFFSET knob.
19. Keeping the U_F , G_1 and U_{GA} fixed, slowly vary the acceleration voltage G_2 and record the corresponding plate current.

Note: Sometimes due to double and multiple collisions of electrons and combinations of excitation of 3S level and 3P level, there may be small variations in plate current

measured in nano-ampere. In such case, take the mean of minimum and maximum readings keeping G2 constant.

20. Repeat the experiment for different filament voltage, G1 or UGA. After setting all the parameters, switch on the ON/OFF switch before taking the readings.
21. Analyze the curve to obtain explicit values of the maxima and minima of the curve.

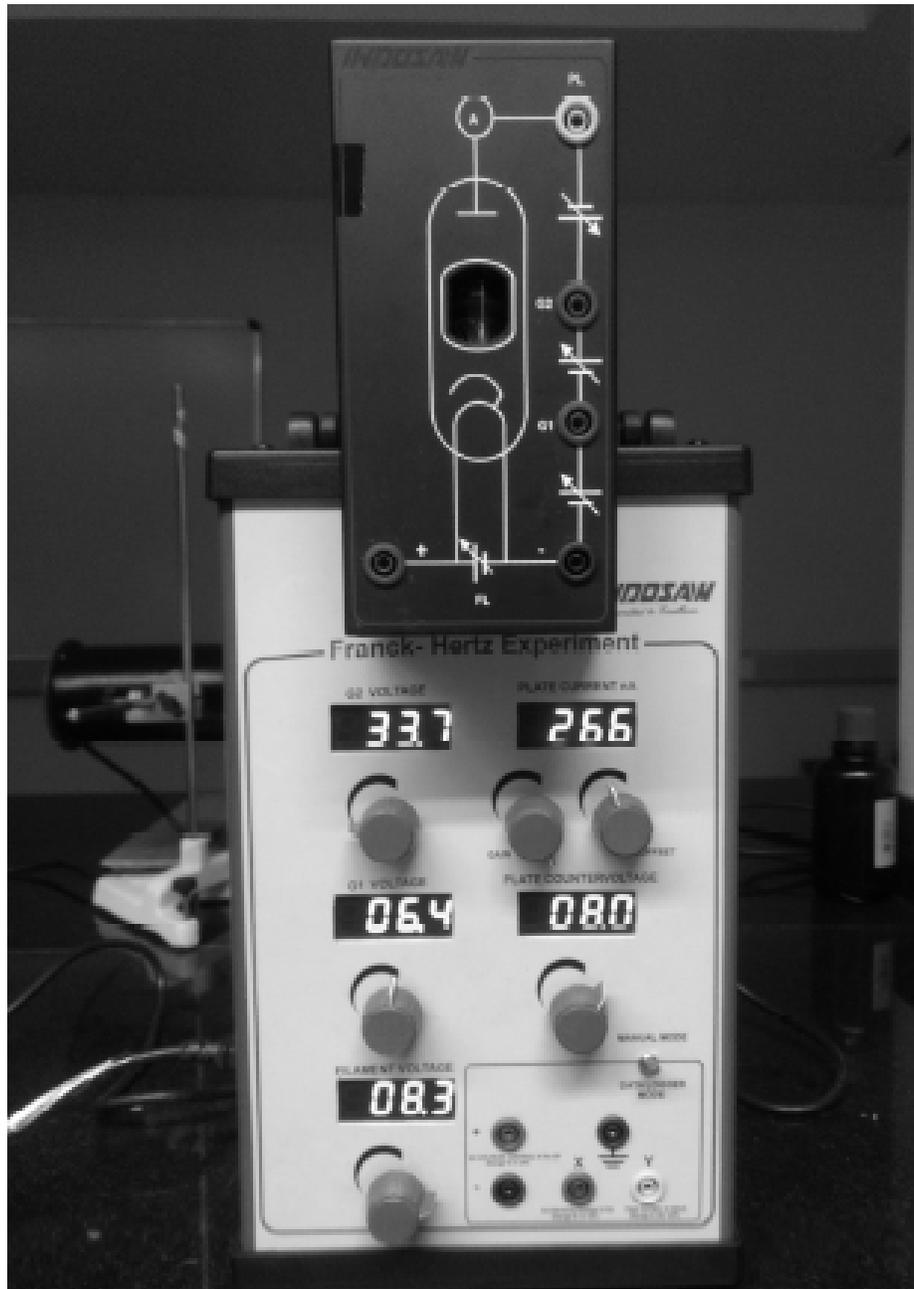


Figure 5: Franck-Hertz experiment setup

6.6 OBSERVATION

Table 1

Accelerating voltage, G2 (V)	..	..	..	..
Plate current (nA)			..	..

$$U_F = _, \quad G1 = _, \quad U_{GA} = _$$

6.7 CALCULATION

Plot plate current ~ accelerating voltage. A sample graph is shown in Figure 6.

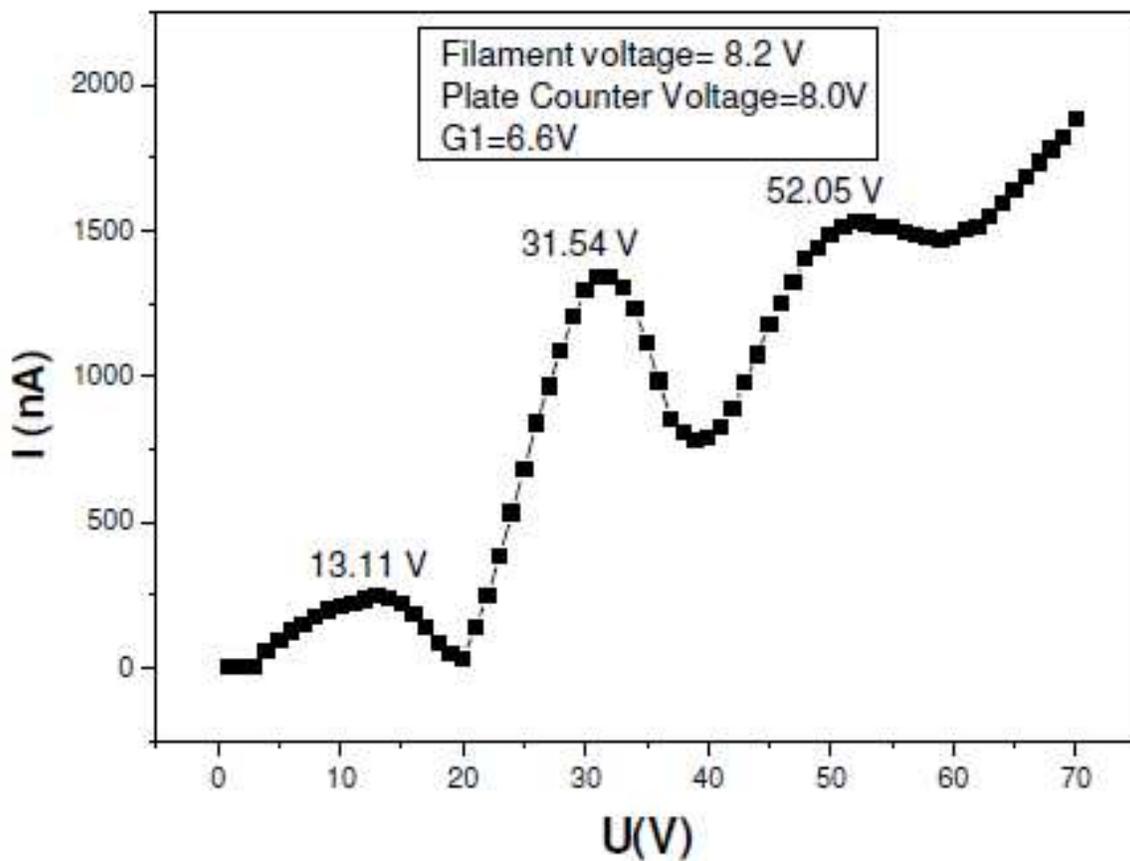


Figure 6: Sample graph

6.8 RESULT

Determine the distance between two consecutive maxima and calculate the excitation energy. Find the average excitation energy in eV.

6.9 PRECAUTIONS AND SOURCES OF ERROR

6. Vary all the knobs slowly.
7. At no time, should the filament voltage exceed 8.5 V.

6.10 SUMMARY

The Franck-Hertz experiment, first undertaken shortly after Bohr's theory of the atom was presented, provided one of the early indications that atoms had discrete energy levels. In this experiment, electrons were accelerated and passed through mercury vapor, where they lose energy by inelastic scattering in quantized steps as they excite mercury atoms from the ground state to an excited state.

This elegant experiment yielded remarkable results that were key in the early development of quantum theory.

6.11 GLOSSARY

Black-body Radiation – An object that absorbs all radiation falling on it, at all wavelengths, is called a black body. When a black body is at a uniform temperature, its emission has a characteristic frequency distribution that depends on the temperature. Its emission is called black-body radiation.

Bohr Theory – a theory of atomic structure in which the hydrogen atom (Bohr atom) is assumed to consist of a proton as nucleus, with a single electron moving in distinct circular orbits around it, each orbit corresponding to a specific quantized energy state: the theory was extended to other atoms.

Cathode – A cathode is the metallic electrode through which current flows out in a polarized electrical device. Conversely, an anode is the electrode in a polarized electrical device through which current flows in from an outside circuit.

Energy Level Transitions – Electrons in atoms and molecules can change (make transitions in) energy levels by emitting or absorbing a photon (of electromagnetic radiation), whose energy must be exactly equal to the energy difference between the two levels.

Electrons can also be completely removed from a chemical species such as an atom, molecule, or ion. Complete removal of an electron from an atom can be a form of ionization, which is effectively moving the electron out to an orbital with an infinite principal quantum number, in effect so far away so as to have practically no more effect on the remaining atom (ion). For various types of atoms, there are 1st, 2nd, 3rd, etc. ionization energies for removing the 1st, then the 2nd, then the 3rd, etc. of the highest energy electrons, respectively, from the atom originally in the ground state. Energy in corresponding opposite quantities can also be released, sometimes in the form of photon energy, when electrons are added to positively charged ions or sometimes atoms. Molecules can also undergo transitions in their vibrational or rotational energy levels. Energy level transitions can also be nonradioactive, meaning emission or absorption of a photon is not involved.

Inelastic Scattering – In chemistry, nuclear physics, and particle physics, inelastic scattering is a fundamental scattering process in which the kinetic energy of an incident particle is not conserved (in contrast to elastic scattering). In an inelastic scattering process, some of the energy of the incident particle is lost or increased.

Quantum Theory – Quantum theory is the theoretical basis of modern physics that explains the nature and behavior of matter and energy on the atomic and subatomic level. The nature and behavior of matter and energy at that level is sometimes referred to as quantum physics and quantum mechanics.

6.12 REFERENCES

1. American Journal of Physics, 56(8), August 1988.
2. D. Halliday and R. Resnick: Fundamental of Physics, New York, John Wiley, 3rd edition 1988, pp. 491-492.
3. R. Eisberg and R. Resnick: Quantum physics of Atoms, Molecules, Solids, Nuclei and Particles, pp 107-110 (F-H effect in Hg), pp 407-409.
4. D. W. Preston and E. R. Dietz: the art of Experimental Physics, Experiment 6, pp 197-208.

6.13 VIVA-VOCE QUESTIONS AND ANSWERS

1. What is the energy level of an electron?

Ans: Energy levels inside an atom are the specific energies that electrons can have when occupying specific orbitals. Electrons can be excited to higher energy levels by absorbing energy

from the surroundings. Light is emitted when an electron relaxes from a high energy state to a lower one.

2. Why is it important to know Planck's constant?

Ans: The Planck constant (Planck's constant) links the amount of energy a photon carries with the frequency of its electromagnetic wave. It is named after the physicist Max Planck. It is an important quantity in quantum physics. In SI Units the Planck constant is about 6.62606×10^{-34} J.

3. The graph below shows the relationship between the frequency of radiation incident on a photosensitive surface and the maximum kinetic energy of the emitted photoelectrons.

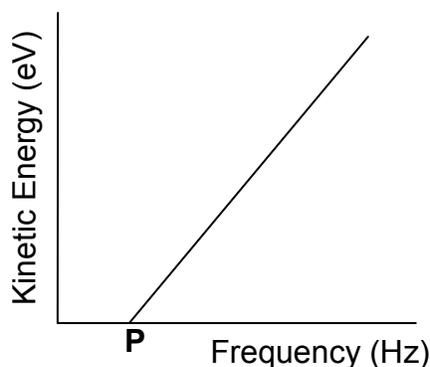


Figure 7

What does point P represent?

Ans: Threshold Frequency

4. What is photoelectric effect?

Ans: The photoelectric effect is a phenomenon in physics. The effect is based on the idea that electromagnetic radiation is made of a series of particles called photons. When a photon hits an electron on a metal surface, the electron can be emitted. The emitted electrons are called photoelectrons.

5. As the Franck-Hertz data shows, when the accelerating voltage reaches threshold value, the current sharply drops, indicating the sharp onset of a new phenomenon which takes enough energy away from the electrons that they cannot reach the collector. This drop is attributed to which phenomena?

Ans: This drop is attributed to inelastic collisions between the accelerated electrons and atomic electrons in the mercury or neon atoms. The sudden onset suggests that the mercury or neon

electrons cannot accept energy until it reaches the threshold for elevating them to an excited state.

Experiment 7: Determination of Susceptibility

Structure

7.1 Objectives

7.2 Introduction

7.3 Apparatus Used

7.4 Theory and Formula Used

7.5 About apparatus

7.6 Procedure

7.7 Observation

7.8 Calculation and Discussion

7.9 Result

7.10 Precaution and source of error

7.11 Summary

7.12 Glossary

7.13 References

7.14 Viva-voce questions and Answers

7.1 Objectives:

After performing this experiment, you should be able to

- understand properties of magnetic materials
- describe susceptibility
- understand the susceptibility of paramagnetic material depends on temperature applied magnetic field
- determine susceptibility for a given paramagnetic solution

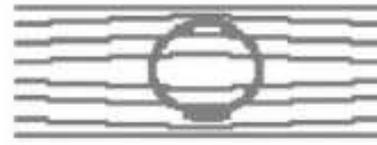
7.2 Introduction:

Magnetic Behavior of Magnetic Materials:

Magnetism is a characteristic property of matter. All substances are broadly classified as Diamagnetic, Paramagnetic, and Ferromagnetic materials on the basis of their magnetic properties or reaction under the influence of applied magnetic field.

Diamagnetic materials

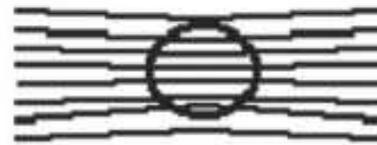
These materials do not show any magnetic behavior in the absence of external magnetic field but exhibit a negative interaction or repulsion with the magnetic field when external magnetic field is applied. In other words, they are slightly repelled in the presence of magnetic field. These substances are said to have a negative magnetic susceptibility of the order of 10^{-6} .



Diamagnetic

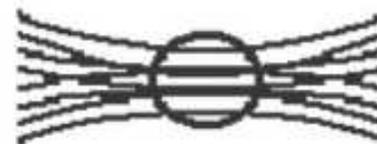
Paramagnetic substances:

Similar to diamagnetic substance, paramagnetic substances also exhibit no magnetic behavior in the absence of external magnetic field. When placed in a magnetic field, these substances are slightly attracted towards the magnetic field. They intensify the applied magnetic field on passing through it. These substances have a positive magnetic susceptibility.



Paramagnetic

Ferromagnetic substances:



Ferromagnetic

Ferromagnetic substances exhibit a different behavior to paramagnetic or diamagnetic substances. When placed in a magnetic field they become strongly attracted in the direction of applied magnetic field. The local magnetic field in the center of the substance is greatly increased. These substances (such as iron, cobalt, nickel etc) retain magnetic properties even after the removal of applied magnetic field. Ferro-magnets are able to retain a permanent magnetic field since their free electrons are in close proximity and remain aligned after the external magnetic field is removed. Unlike the Ferro-magnets, Diamagnetic or Paramagnetic materials shows exhibits magnetic properties only in the presence of applied magnetic field which could be observed and measured.

Magnetic Susceptibility:

Magnetic susceptibility is a quantitative measure of the extent to which a material may be magnetized with applied magnetic field. The magnetic susceptibility of a material is the ratio of the magnetization M within the material to the applied magnetic field strength H . It is generally symbolized by χ_m

$$\chi_m = \frac{M}{H}$$

This ratio, strictly speaking, is the volume susceptibility.

Magnetic susceptibility is the degree to which a material can be magnetized in an external magnetic field. If the ratio of the magnetization is expressed per unit volume, volume susceptibility is defined as,

$$\chi_v = M / H,$$

Where M is the volume magnetization induced in a material of susceptibility k by the applied external field H .

7.3 Apparatus Used:

Quinck's tube with stand, Ferric chloride sample, Electromagnet, Gauss and Tesla meter, InAs Probe, Constant current power supply, magnifying viewer, Travelling Microscope (Optional), Graduated cylinder.

7.4 Theory and formula used:

The method of Quinck's is used to determine magnetic susceptibility of aqueous solution (liquid form) of diamagnetic and paramagnetic substances. This method is based on the measurement of induced magnetic moment when an object is placed in a magnetic field. The magnetic susceptibility of a material is the ratio of the magnetization (*magnetic moment per unit volume*) within the material to the applied magnetic field strength H . The induced magnetic moment can be measured using force methods. The measurement of the force exerted on the sample due to applied magnetic field is negative of the gradient of the change in energy density when the sample is placed,

$$f = \frac{d}{dx} \left[\frac{1}{2} \mu_0 (\mu_r - \mu_{ra}) H^2 \right] = \frac{1}{2} \mu_0 (\chi - \chi_0) \frac{d}{dx} H^2 \quad (1)$$

Here μ_0 is permeability of the free space. μ_r, χ are relative permeability and susceptibility of the sample. μ_{ra} , relative permeability of the air. The force acting on an element of area A and length dx of the liquid column is $fAdx$, so the total force F on the liquid is

$$F = A \int f dx = \frac{A \mu_0}{2} (\chi - \chi_0) (H^2 - H_0^2) \quad (2)$$

Where, the integral is taken over the whole liquid. This means that H is equal to the field at the liquid surface between the poles of the magnet and H_0 is the field at the other surface away from the magnet. The liquid (density ρ) moves under the action of this force until it is balanced by the pressure exerted over the area A due to a height difference h between the liquid surfaces in the two arms of the U-tube. It follows that

$$F = Ah(\rho - \rho_a)g$$

Or

$$\chi = \chi_a + \frac{2}{\mu_0} g(\rho - \rho_a) \frac{h}{(H^2 - H_0^2)}. \quad (3)$$

Density of air ρ_a , χ_a and H_0 are negligible in actual practice and can be ignored and the above expression simplifies to

$$\chi = \frac{2(\rho - \rho_a)gh}{H^2}$$

Where ρ = density of the liquid

ρ_a = density of air

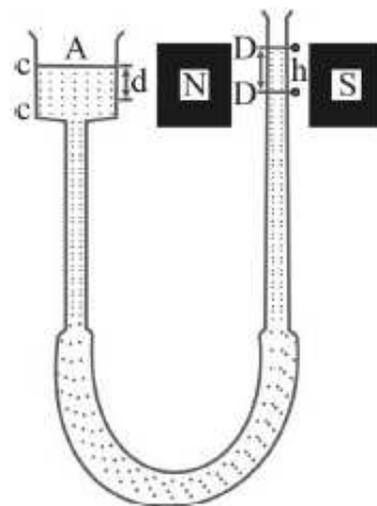
g = gravitational acceleration.

h = rise of the sample liquid column in narrow tube due to application of magnetic field.

H = strength of applied magnetic field between the pole pieces.

7.5 About apparatus:

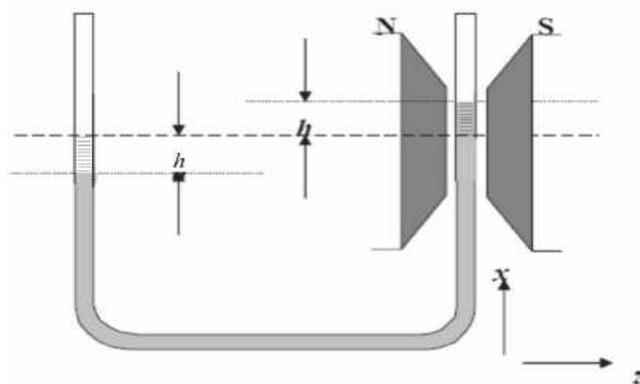
The apparatus to determine the magnetic susceptibility consists of Quincke's tube and a pair of electromagnets. The U shaped Quincke's tube is used to keep the liquid form of sample and a in which the sample is taken. This tube is has two limbs, one with very narrow width compared to the other. Therefore, any change in the liquid level in the narrow limb does not affect the level in the wider limb. A digital gauss meter is also used for the measurement of applied magnetic field across the narrow limb. The rise in sample liquid due to application of magnetic field is observed using a travelling microscope.



7.6 Procedure:

Let us perform the experiment in following steps.

1. Take Gauss and Tesla meter.
2. Connect InAs probe and switch on the Gauss or Tesla meter.
3. Adjust zero reading on display by zero adjusts potentiometer and keep range selector switch at X_1 position.
4. Now take Constant Current Power Supply and set the current Adjust potentiometer at fully anticlockwise position. Connect electromagnet is in series i.e. the direction of current in both the coil of electromagnet is in the series i.e. the direction of current in both the coils should be same otherwise little or no magnetic field would result.
5. Switch on the Power Supply and set some low value of current.
6. Keep Hall probe (InAs) between electromagnet to measure the strength of magnetic field.
7. Increase the current from the Constant Current Power Supply and note the value of corresponding magnetic field. If magnetic field is greater than 2K gauss then meter will indicate the over range. For its measurement keep the selector switch at X_{10} position and note the value of magnetic field.
8. Multiply the display reading by 10 to get the magnetic field strength in both gauss and tesla.
9. You get result that magnetic field increase with increasing current of electromagnet.
10. Now switch off the Constant Current Supply and Gauss and Tesla meter, as it is ready for measurement.



Paramagnetic liquid in a uniform magnetic field

11. Now for preparing the solution of ferric chloride, take distilled water, graduated cylinder and ferric chloride powder.
12. Now make a saturated solution of FeCl_3 by dissolving maximum amount of solvent in the 10 ml distilled water. Any more solute added will sit as crystals on the bottom of the container). Note total mass of FeCl_3 Powder which is dissolve in water.
 $m = \dots\dots\dots\text{gm}$
 Note: Stirring the solution continuously.
13. Mount the Quinck's tube on its stand.
14. Thoroughly clean the Quinck's tube and fill it with FeCl_3 solution with wide limb such that the liquid meniscus lies in the central region of the pole pieces. Note the remaining volume (r) of solution, so that volume of solution inserted into U-tube will be
 $v = (10-r)$ ml
 So density of liquid or solution $\rho = m/v$ and density of air $\rho_a = 1$
15. Insert the narrow limb of U-tube vertically between the pole pieces of the electromagnet.
16. Transfer some of solution to the U-tube so that the meniscus is in the center of the pole pieces if necessary.
17. Ensure that the surface of the liquid is adjusted between the poles of the magnet is where the field is reasonably uniform and maximum.
18. Take magnifier viewer note the reading of the lower meniscus of the liquid (as shown in below figure) by the graduated scale on the limb and put into the observation table given below, when no current is passing through electromagnet. Illuminate the meniscus with an electric lamp (if necessary).
19. Now switch on the constant current supply and Gauss and Tesla meter and observe rise in level of liquid for 1A current. Note the reading of the lower meniscus of the liquid and put into the below table.
20. Repeat the experiment for different values of magnetizing current.
21. Now remove the U-shape tube and place as probe between the electromagnet as describe above and note magnetic field (H) in below table.

7.7 Observation:

Table: Determination of magnetic susceptibility

S.No	Magnetizing current I amp	Magnetic field H	H^2	Position of liquid meniscus		Height of liquid column $h = a-b$	Susceptibility $\chi = \frac{2(\rho - \rho_a)gh}{H^2}$
				Without field (a)	With field (b)		
1							
2							
3							
4							

5							
6							

7.8 Calculation and Discussion:

Based on the above observation table, a graph is plotted between the height of the liquid column (h) versus H^2 , which comes out to be a straight line. The slope of the straight line will be the average value of h/H^2 .

Now, the susceptibility of the given paramedical solution can be calculated with the help of given formula: $\chi = \frac{2(\rho - \rho_0)gh}{H^2}$.

7.9 Result:

Mean susceptibility $\chi = \dots\dots\dots$

7.10 Precaution and source of error:

1. Don't touch powder or solution, chemical gloves recommended.
2. Read the microscope reading carefully.

7.11 Summary:

1. The Quinck's Method is used to determine magnetic susceptibility of paramagnetic substance in the form of a liquid or an aqueous solution.
2. This method is based on the force experienced by a magnetized material in a non-uniform magnetic field.
3. A magnetic moment induce in the paramagnetic solution under the influence of external magnetic field.
4. The magnetic susceptibility is a dimensionless quantity which indicates the degree of magnetization in a material when an external magnetic field applied.
5. A liquid sample in a narrow tube placed between the poles of a magnet experiences a force and hence when the field is turned on, the meniscus in the narrow tube rises by an amount h, relative to its zero-field position.
6. Measuring this rise enables to determine the susceptibility of the solution.

7.12 Glossary

Least count: The minimum value can be measured by any instrument.

Susceptibility: It is degree of magnetization of a material on application of applied magnetic field.

Gauss and Tesla: The CGS and SI units of magnetic field.

Bohr magnetron: The smallest unit to measure magnetic field.

Magnetic moment: The magnetic moment is the magnetic strength and orientation of a magnet or other object that produces a magnetic field

7.13 References:

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi
2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi
3. Indu Prakash, Ram Krishna, A. K. Jha, *A text Book of Practical Physics*, Kitab Mahal Publication Delhi.
4. User's manual by Scientific equipment and services Roorkee.
5. Lab manual by IISER Kolkata.

7.14 Viva-voce questions:

1. What do you mean by magnetic susceptibility?

Ans : The magnetic susceptibility χ is a dimensionless proportionality constant that indicates the degree of magnetization of a material in response to an applied magnetic field.

2. What is magnetization and magnetic intensity?

Ans: The magnetic dipole moment per unit volume of the magnetized substance is called magnetization (M). Magnetic field intensity (H) refers to the strength of applied magnetic field.

3. What is the relation between magnetic flux density, magnetic intensity and magnetization?

Ans: The relation is

$$B = \mu_0(H + M)$$

Where B = magnetic flux density, H = Magnetic field intensity, M = magnetization and μ_0 = permeability of free space.

4. What is permeability?

Ans: The magnetic permeability (μ) deals with the degree of concentration of lines of force in a specimen. It is the ratio of the number of lines of force passing per unit area (held perpendicular to the lines of force) in the specimen to the lines of force that would exist there due to the field in the absence of specimen. In the other way, it is the inductance per

unit length. In SI units, permeability is measured in henrys per metre ($\text{H}\cdot\text{m}^{-1} = \text{J}/(\text{A}^2\cdot\text{m}) = \text{N A}^{-2}$).

5. How the magnetic permeability is related with magnetic susceptibility?

Ans: The relation is given as $\mu = \mu_0(1 + \chi)$

where μ is magnetic permeability of the medium, μ_0 is magnetic permeability of free and χ magnetic susceptibility of the material. Also relative magnetic permeability (μ_r) of the medium is represented by $\mu_r = \mu / \mu_0$

6. What are paramagnetic substances or paramagnetic salts?

Ans: Paramagnetic substances are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed. These have a small, positive susceptibility to magnetic fields. Paramagnetic properties are due to the presence of some unpaired electrons, and from the realignment of the electron paths caused by the external magnetic field. Paramagnetic materials include magnesium, molybdenum, lithium, and tantalum.

Similarly, a paramagnetic salt is a salt that has free paramagnetic ions. In the absence of a strong magnetic field these ions or magnetic dipoles are randomly aligned, thus giving a net value of zero for the magnetization of the salt.

7. What are diamagnetic and ferromagnetic substances?

Ans: A substance which when placed in the magnetic field gets feebly magnetized in the direction opposite to the applied magnetic field, is called diamagnetic substance eg. Al, Mn, CuCl_2 , O_2 etc.

The ferromagnetic substances are those substances which when placed in the magnetic field, become strongly magnetized in the direction of the field eg. Fe, Ni, Co etc.

8. How will you distinguish paramagnetic, diamagnetic and ferromagnetic substances in the light of susceptibility?

Ans: Ferromagnetic substances have large positive susceptibility. Sometimes in some cases may as high as 10^5 . Paramagnetic substances have a small, positive susceptibility. The diamagnetic substances exhibit small, negative magnetic susceptibility of the order of 10^{-5} .

Experiment 8: Velocity of ultrasonic waves

Structure

8.1 Objectives

8.2 Introduction

8.3 Apparatus Used

8.4 Theory and Formula Used

8.5 About apparatus

8.6 Procedure

8.7 Observation

8.8 Calculation and Discussion

8.9 Result

8.10 Precaution and source of error

8.11 Summary

8.12 Glossary

8.13 References

8.14 Viva-voce questions and Answers

8.1 Objectives:

After performing this experiment, you should be able to

- understand the principle of interference.
- understand the principle of acoustical grating.
- determine the velocity of the ultrasonic waves in the liquid.

8.2 Introduction:

Ultrasonic waves are not audible to humans. The vibrations of frequencies in ultrasonic waves are greater than 20000 Hz. The general principle involved in producing the ultrasonic waves can be produced by generating rapid vibrations in some dense materials. The production of these waves is based on the fast vibrations of some crystals of specific materials such as quartz when electricity is passed through them. This is known as piezoelectric behavior and phenomenon is known as piezoelectricity. These vibrations in material can produce ultrasonic waves in the air the air around them and the fluids they come in contact with. The Devices that produce ultrasonic waves are known as piezoelectric transducers.

8.3 Apparatus Used:

Ultrasonic interferometer, measuring cell, frequency generator, given liquid, etc.

8.4 Theory and formula used:

An Ultrasonic Interferometer is a simple and direct device used to determine velocity of Ultrasonic waves in liquid in a very precise manner. (Fig. 1).

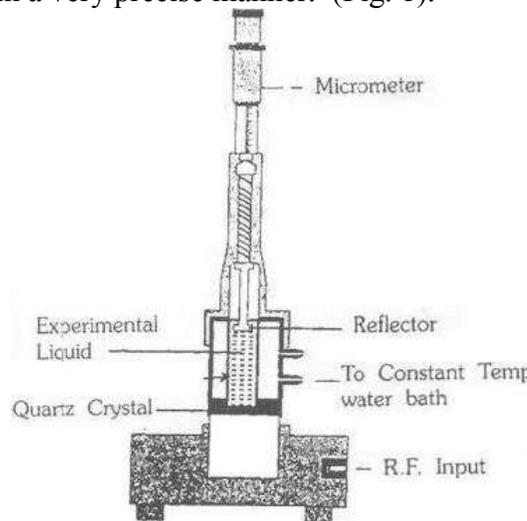


Figure 1

The principle used in measurement of the velocity (v) is based on the accurate determination of the wavelength in the liquid. The quartz crystal is used to produce the ultrasonic waves of known frequency at the bottom of the cell. These waves are then reflected by movable metallic plate kept parallel to the quartz crystal. If the separation between these two plates is exactly a whole multiple of the wavelength of ultrasonic waves, standing waves are formed in the liquid. This acoustic resonance gives rise to an electrical reaction on the generator driving the quartz crystal and the anode current of the generator becomes maximum. If the distance varies and the variation is exactly one half wavelength ($\lambda/2$) or multiple of it, anode current becomes maximum. For the knowledge of this distance, the velocity of ultrasonic waves in liquid can be calculated as follows:

$$v = \frac{2d}{n} \times f$$

(v)

Where,

$\lambda = 2d/n$ = Wavelength of the ultrasonic wave in (m)

f = Frequency of ultrasonic waves in (Hz)

d = Distance moved by the micrometer screw in (m)

n = Number of oscillations ρ is the density of the given liquid in kgm^{-3}

8.5 About apparatus:

The apparatus in the experiment is a simple electric circuit as shown in figure 1. The 6V battery is connected to the electric bulb with rheostat. For the measurement of current and voltage the DC Voltmeter (0-10V) & DC ammeter (0-1 A) are connected.

8.6 Procedure:

Perform the experiment in following steps.

1. Connect the measuring cell to the output of high frequency generator through a shielded cable.
2. Fill the cell with the experimental liquid. Now, switch ON the generator. Now, the ultrasonic waves move normal from the Quartz crystal and reflected back by the movable reflector plate. Hence, standing waves are formed in the liquid in between the reflector and the quartz crystal.
3. Using the micrometer screw, adjust the distance between the crystal and reflector such that the anode current of the generator increases to a maximum and then decreases to a minimum and again increases to a maximum.
4. The distance of separation between successive maximum or successive minimum in the anode current is equal to half the wavelength of the ultrasonic waves in the liquid. (see Fig. 2).
5. The distance moved by the reflector for one complete oscillation (maxima—minima—maxima) can be determined by noting the initial and final positions of reflector using micrometer screw.
6. Now, the distance (d) moved by the micrometer screw is noted for 'n' number of successive maxima to minimize the error and is tabulated.
7. The wavelength of ultrasonic waves can be determined using the formula $\lambda = 2d/n$ by substituting the values of the total distance (d) moved by the micrometer screw and the number of oscillations (n), from the value of k and by noting the frequency of the generator (f).
8. By using the frequency of the generator (f), and wavelength (λ) calculated above, the velocity of the ultrasonic waves and of the given liquid can be calculated using the given formula.

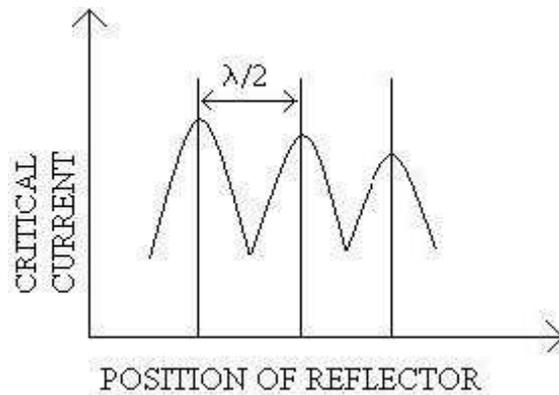


Figure:2

8.7 Observation:

Least count of main scale =

Total number of divisions in circular scale =

Least count of the instrument (LC) =

Table1. To find the velocity of Ultrasonic waves in the liquid

S.No.	Crystal current (μA)	Position of the reflector		
		MSR (x) in mm	Circular scale Reading (y) in mm	Final reading (mm) $x+y \times LC$
1				
2				
3				
4				
5				

8.8 Calculation and Discussion:

(i) Wavelength of the Ultrasonic waves =

Frequency of Ultrasonic waves =

The velocity of Ultrasonic waves in the given liquid, v =

8.9 Result:

The velocity of Ultrasonic waves in the given liquid is

8.10 Precaution and source of error:

1. The distance between the reflector and crystal is varied extremely slowly using the micrometer screw to get the exact position of maximum deflection in micro ammeter.
2. The points of maximum and minimum readings are taken very precisely.
3. The micro ammeter is initially set to a higher and observable value so that the dropping in current can be observed in precise manner.

8.11 Summary:

1. The velocity of ultrasonic waves in liquid and air can be determined using a simple and direct device known as Ultrasonic Interferometer.
2. In Ultrasonic Interferometer, a variable range of frequencies can be generated using a high frequency generator.
3. This variable frequency then excites the Quartz crystal placed at the bottom of the measuring cell.
4. The excited and vibrated Quartz crystal generates ultrasonic waves in the air the air around them or the fluids they come in contact with.
5. Standing waves are formed in the medium between the reflector and the quartz crystal in ultrasonic interferometer.
6. The distance between successive maxima and minima in standing wave can be determined.
7. The velocity of ultrasonic waves can be determined in the experimental liquid using the formula given in section 1.4

8.12 Glossary

Ultrasonic waves: a wave with frequency 20000 Hz and ahead.

Interferometer: a device to produce interference.

8.13 References:

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi
2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi
3. Indu Prakash, Ram Krishna, A. K. Jha, *A text Book of Practical Physics*, Kitab Mahal Publication Delhi.
4. <https://en.wikipedia.org>

8.14 Viva-voce questions:

1. What are ultrasonic waves?

Ans: The sound waves having frequency more than 20,000 Hz are known as ultrasonic waves. Ultrasonic waves are not audible to human ear.

2. What is piezo electric effect?

Ans: When a mechanical stress is applied to opposite sides of a Quartz crystal, electric charges are induced. This phenomenon is known as piezo electric effect.

3. What is resonance condition to produce Ultrasonic waves in a piezo electric oscillator?

Ans: The resonance is condition is that the natural frequency of vibration of Quartz must be matched with frequency of oscillatory tank circuit.

Experiment 9: Michelson Morley experiment

Structure

9.1 Objectives

9.2 Introduction

9.3 Apparatus Used

9.4 Theory and Formula Used

9.5 About apparatus

9.6 Procedure

9.7 Observation

9.8 Calculation and Discussion

9.9 Result

9.10 Precaution and source of error

9.11 Summary

9.12 Glossary

9.13 References

9.14 Viva-voce questions and Answers

9.1 Objectives:

After performing this experiment, you should be able to

- understand the principle of interference.
- measurement of the wavelength of He-Ne Laser using circular fringes.

9.2 Introduction:

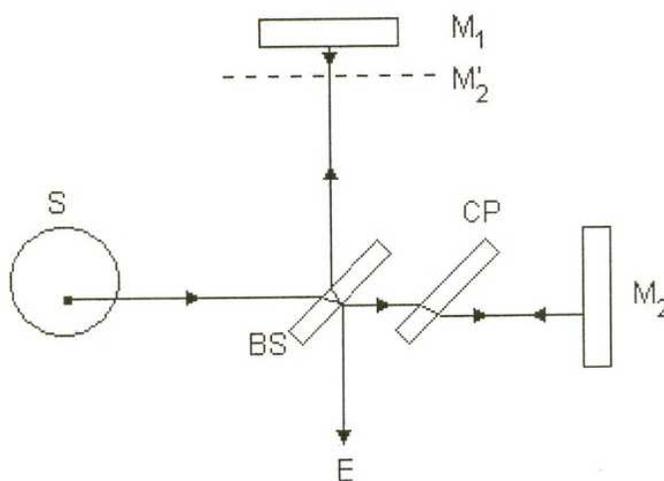
Light is an electromagnetic wave with transverse nature. When two waves of same wavelength and amplitude from coherent sources and moving in the same direction superimpose at a point, their amplitudes combine. This result to form a combined wave of greater or lesser amplitude than the original. This phenomenon is called interference and the instruments based upon the on interference are known as interferometers. Interferometers are generally used to measure the wavelength of optical beams in a precise manner. Based on the formation of coherent sources, interferometers are further divided into wavefront splitting and amplitude splitting interferometers. Michelson interferometer comes in the category of amplitude-splitting interferometers devised by Albert Michelson in 1890. This versatile instrument was also used to establish experimental evidence for the development for the validity of the special theory of relativity, to detect and measure speed of light in Aether (a hypothetical medium around the universe assumed that time).

9.3 Apparatus Used:

Laser light source, Michelson interferometer kit, optical bench, meter scale.

9.4 Theory and Formula Used:

Light from a monochromatic source S is divided by a 45° oriented compensatory glass plate known as beam splitter (BS) to produce two beams of equal intensity. The rear side of glass plate BS is semi-silvered such that the light from a source is equally reflected and transmitted by it. This interferometer also consists of two fully silvered mirrors M_1 and M_2 which can be moved back and forth to observe the change in fringes. One of the beam reflected towards the mirror M_1 and the other is transmitted towards mirror M_2 . The two beams are then reflected back by the mirrors M_1 and M_2 and return to the plate BS. The ray reflected from M_1 is transmitted through BS and the ray reflected from M_2 is reflected again by BS. The two rays coming from the two mirrors interfere and fringes are observed on a screen or by naked eye at E . The relative phase of the two beams determines whether the interference will be constructive or destructive. By adjusting the inclination of M_1 and M_2 , one can produce circular fringes, straight-line fringes, or curved fringes. The mirrors are mounted such that can be moved.





The reflected beams from M_1 and entering the eye/screen passes beam splitter glass plate (BS) twice. However the other wave reflecting from the mirror M_2 travels totally in air. To compensate this path difference, a compensating plate CP of same thickness as that of BS is also introduced. Thus, the two beams will interfere constructively or destructively as per the following conditions of path difference, Δ

$$\Delta = n\lambda \quad \dots (\text{for bright fringe, } n \text{ is an integer})$$

$$\Delta = (2n+1)\lambda/2 \quad \dots (\text{for dark fringe, } n \text{ is an integer})$$

To determine the wavelength of light from a monochromatic source using the Michelson interferometer can be determined, the mirror M_1 (or M_2) is moved forward or backward. Due to mirror movement, fringes pattern shifted with appear or disappear at the centre of circular fringe pattern. If N of fringes appearing or disappearing at the centre due to moved distance d and the number is counted and for one fringe to appear or disappear, the mirror must be moved through a distance of $\lambda/2$. we can write,

Hence,

$$d = N\lambda/2$$

$$\text{Or,} \quad \lambda = (2d)/N$$

9.5 About apparatus:

The apparatus consists of a He-Ne laser on an adjustable mount, a screen, Michelson interferometer kit which includes mirror (M_1) whose tilt is adjustable and can be translated with a screw, mirror (M_2), beam splitter on tilt adjustable mounts. The Mirror M_2 is fitted with a micrometer screw for precise translation of the mirror with sub-micrometer precision via a lever.

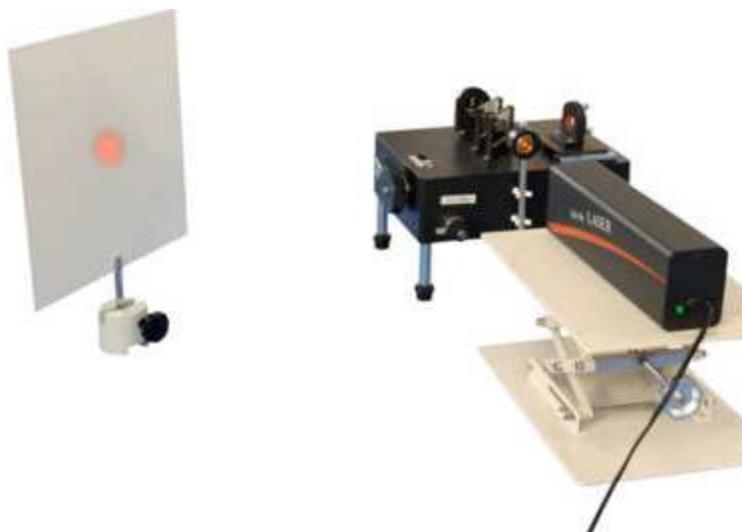


Fig: Experimental set up Michelson interferometer kit with Laser light source

9.6 Procedure:

Let us perform the experiment in following steps to find the wavelength of the laser source:

1. The laser beam must strike at the centre of the movable mirror and should be reflected directly back into the laser aperture.
2. Adjust the position of the beam splitter so that the beam is reflected to the fixed mirror.
3. Adjust the angle of beam splitter to be 45 degrees. There will be two sets of bright spots on the screen, one set from the fixed mirror and another from the movable mirror.
4. Adjust the angle of the beam splitter to make the two sets of spots as close together as possible.
5. With the screws on the back of the adjustable mirror, adjust the mirror's tilt until the two sets of spots on the screen coincide.
6. Expand the laser beam slowly by rotating the collimating lens in front of the laser.
7. Align the laser with the interferometer and make certain that the fringes are moving when the micrometer screw is turned.
8. Mark a point on the screen and note the micrometer reading.
9. As the screw is moved, the fringes begin to displace. Count the number of fringes N that move past the mark (either inward or outward). To avoid the effects of backlash in the micrometer screw, turn the micrometer handle one full turn before starting the count.
10. Note the micrometer readings at the beginning and end of the count. Calculate the distance d' the mirror is moved, according to the beginning and ending micrometer readings. Repeat the procedure several times. Average the readings.
11. With a known wavelength laser, use $d = N\lambda/2$ to calculate the actual distance moved. The calibration constant of the interferometer is then $k = d/d'$. All subsequent distance measurements with the micrometer should be multiplied by the calibration constant k . Ideally, k would be exactly 1, but factors such as wear and thermal expansion can cause it to vary.
12. Once the calibration constant is known, if the laser source has an unknown wavelength, it can be calculated with the same equation.

9.7 Observation:

Least Count = cm

Calibration constant of the apparatus=

No: of fringes, $N = \dots$

Distance moved for N fringes, $d = \dots$ cm.

Then, $\lambda = 2\Delta d/N$

Table 1

S.No.	PSR (cm)	HSR(div)	Distance moved in cm	Difference (d) in cm

9.8 Calculation and Discussion:

The wavelength of laser light source can be determined with the help of Michelson interferometer. Due to movement of mirror, a path difference is established between the reflecting beams from the mirrors which results in fringe shifting. The fringe count can be given by $\Delta = N\lambda = 2d$, where Δ is the path difference that occurs when ' N ' fringes pass as the micrometer is moved through a distance of ' d '.

9.9 Result:

The wavelength of the given laser source = nm.

λ for He-Ne laser =

Standard value: λ for laser = 632.8 nm

% error=

9.10 Precaution and source of error:

3. To count fringes, adjustment knob should be adjusted in proper way.
4. Always complete the one side of turn (evolution) before counting.
5. Always turn the fine adjustment knob in one direction either clockwise or anti-clockwise.
6. Always Avoid the direct exposure of eye to laser.
7. Avoid touching any of the glass surface with bare hand.

9.11 Summary:

1. Using the Michelson interferometer, the wavelength of light from a monochromatic source can be determined.
2. Michelson interferometer comes in the category of amplitude-splitting interferometers devised by Albert Michelson in 1890.
3. When two waves of same wavelength and amplitude from coherent sources and moving in the same direction superimpose at a point, their amplitudes combine. This is known as interference of light.

4. The two waves will interfere constructively or destructively as per the following conditions of path difference, Δ

$$\Delta = n\lambda \quad \dots (\text{for bright fringe, } n \text{ is an integer})$$

$$\Delta = (2n+1)\lambda/2 \quad \dots (\text{for dark fringe, } n \text{ is an integer})$$

5. The mirror is moved through a known distance d and the number N of fringes appearing or disappearing at the centre is counted. For one fringe to appear or disappear, the mirror must be moved through a distance of $\lambda/2$. Knowing this, we can write,

Hence,

$$\lambda = 2d/N$$

9.12 Glossary:

Coherent sources: Two sources emitting waves with same frequency and waves.

Interferometer: An instrument based on interference principle.

Beam splitter: A plane glass plate which can split the light due to reflection and transmission.

Fully silvered mirrors: Mirrors which can reflect light waves almost 100%.

Aether: a hypothetical medium around the universe assumed that time

9.13 References:

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi
2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi
3. W. Steel, *Interferometry*, Cambridge Cambridgeshire New York: Cambridge University Press, 1983
4. <http://vlab.amrita.edu/>

9.14 Viva-voce questions:

1. What does a Michelson Interferometer physically do?

Ans: Michelson Interferometer used to form two coherent sources from one source and the allowed the wave emitting from these sources to superimpose and produce interference pattern. Hence, this may be use as a technique to measure the wavelength of optical beams in a precise manner

2. What is the purpose of a half-silvered mirror in Michelson Interferometer?

Ans: Half silvered mirror used in Michelson Interferometer is called beam splitter (BS). It is used to produce two beams of equal intensity. The rear side of glass plate BS is semi-silvered such that the light from a source is equally reflected and transmitted by it.

3. Give some of the uses of the interferometer?

Ans: This versatile instrument was also used to establish experimental evidence for the development for the validity of the special theory of relativity, to detect and measure hyperfine structure in line spectra and to detect the gravitational waves etc.

4. What is the conclusion of Michelson and Morley's experiment?

Ans: The Michelson and Morley's experiment pointed towards a negative result to the established Aether theory (the speed of light is also relative) that time. Later, Einstein proposed in his postulates of special theory of relativity that speed of light is absolute and constant.

Experiment 10:

Study of photovoltaic cell

Structure

- 10.1 Objectives
- 10.2 Introduction
- 10.3 Apparatus Used
- 10.4 Theory and Formula Used
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- 10.14 Viva-voce questions and Answers

10.1 Objectives:

After performing this experiment, you should be able to

- plot current voltage characteristics of photovoltaic cell.
- plot the power voltage characteristic of photovoltaic cell.

- determine the fill factor and efficiency of photovoltaic cell.

10.2 Introduction:

A solar cell or photovoltaic cell is a device that converts light energy into electrical energy. Sometimes the term solar cell is reserved for devices intended specifically to capture energy from sunlight, while the term photovoltaic cell is used when the light source is unspecified. Fundamentally, the device needs to fulfill only two functions: photo-generation of charge carriers (electrons and holes) in a light-absorbing material, and separation of the charge carriers to a conductive contact that will transmit the electricity. This conversion is called the *photovoltaic effect*, and the field of research related to solar cells is known as photovoltaic.

10.3 Apparatus Used:

Solar Panel, Table lamp, Digital/Analog D.C ammeter and voltmeter.

10.4 Theory and formula used:

1. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
2. Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity. The complementary positive charges that are also created (like bubbles) are called holes and flow in the direction opposite of the electrons in a silicon solar panel.
3. An array of solar panels converts solar energy into a usable amount of direct current (DC) electricity.

PHOTO GENERATION OF CHARGE CARRIER

When a photon hits a piece of silicon, one of three things can happen:

1. The photon can pass straight through the silicon this (generally) happens for lower energy photons,
2. The photon can reflect off the surface,
3. The photon can be absorbed by the silicon which either generates heat or generates electron-hole pairs, if the photon energy is higher than the silicon band gap value.

CHARGE CARRIER SEPARATION

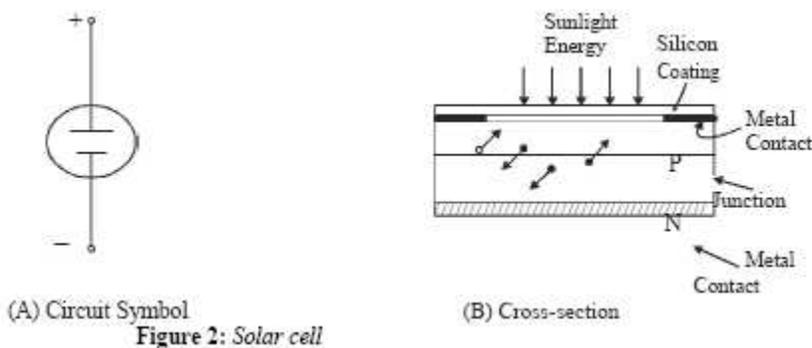
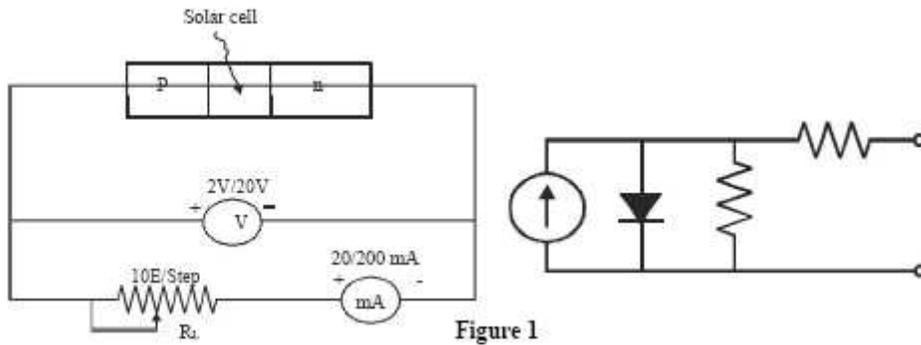
There are two main modes for charge carrier separation in a solar cell:

1. **Drift** of carriers, driven by an electrostatic field established across the device
2. **Diffusion** of carriers from zones of high carrier concentration to zones of low carrier concentration (following a gradient of electrochemical potential).

In the widely used *p-n junction* designed solar cells, the dominant mode of charge carrier separation is by *drift*. However, in *non-p-n junction* designed solar cells (typical of the third

generation of solar cell research such as dye and polymer thin-film solar cells), a general electrostatic field has been confirmed to be absent, and the dominant mode of separation is via charge carrier *diffusion*.

10.5 About apparatus:



10.6 Procedure:

Let us perform the experiment in following steps.

1. Take the Solar Energy Trainer kit along with Solar Panel.
2. Place the solar panel in the stand and adjust the panel at an angle of about 45° with the ground. Direct the sunlight straight at the solar panel (angle of 90°).
Note: If sunlight is not properly available then any source of light like lamp can be used.
3. Set the potentiometer to maximum resistance i.e. at fully clockwise position and measure and record its resistance into the Observation Table.
4. Connect the solar cell as shown in the following circuit diagram as shown in figure 3.
 - a. Connect positive terminal of solar cell to P_1 terminal of the potentiometer.
 - b. Connect other end of potentiometer i.e. P_2 to positive terminal of ammeter.
 - c. Connect negative terminal of ammeter to negative terminal of solar cell.
 - d. Now connect the positive terminal of voltmeter to P_1 and negative terminal of voltmeter to P_2 .
6. Record the values of corresponding voltage and current into the observation Table.

7. Now gradually move the potentiometer in anti- clockwise direction so that the resistance of the potentiometer decreases. Now measure the resistances at successively smaller values and record the corresponding values of voltages and current in the Observation Table below.

Note: Always to measure the resistance of potentiometer at any position, first remove the patch cords from P_1 and P_2 and measure resistance by multi meter. Reconnect these connections again for further measurements.

10.7 Observation:

Table1.

S.No.	Resistance, R	Voltage, V (Volt)	Current, I (mA)	Power Calculated $P = V.I$ (watt)
1				
2				
3				
4				
5				
6				
7				
8				

10.8 Calculation and Discussion:

Plot the V-I characteristics from the measurements recorded in the table, to show how the photoelectric current depends on the photoelectric voltage and to find maximum power point.

Fillfactor Calculation

Fill factor is the ratio of maximum useful power to ideal power. Maximum useful power is the area of largest rectangle that can be formed under V-I curve. V_m and I_m are values of voltage and current for these conditions:

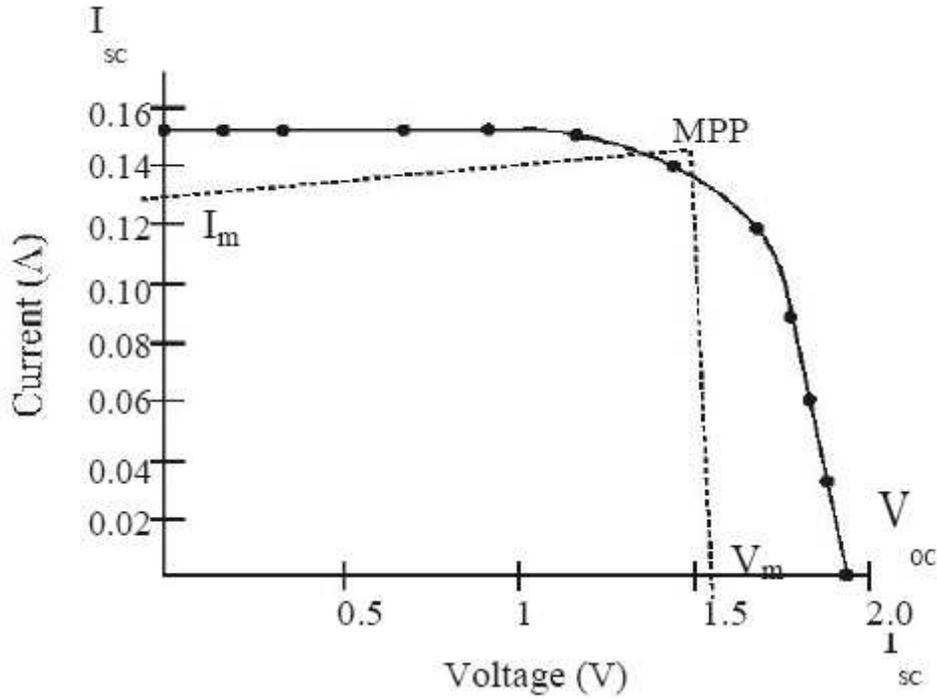


Figure 3: Current voltage characteristic of photovoltaic cell

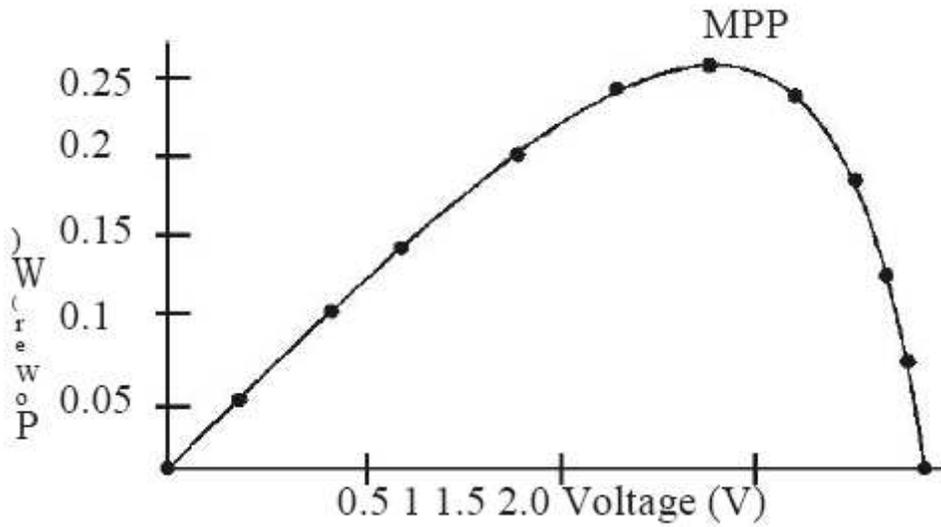


Figure 4: Power voltage characteristic of photovoltaic cell

Maximum useful power = $V_m \times I_m$

And Ideal power = $V_{OC} \times I_{SC}$

Where,

Fill factor = $(V_m \times I_m) / (V_{OC} \times I_{SC})$

The maximum power point (MPP) is the maximum value of power in the above curve.

The resistance, R_{MPP} , at which the output power is at a maximum, can be calculated using the following formula:

$$R_{MPP} = \frac{V_{MPP}}{I_{MPP}}$$

TO CALCULATE THE EFFICIENCY (η) OF SOLAR CELL

The efficiency of the solar cell is the ratio of produced electrical power (P_{out}) and the incident radiant power (P_{in}).

Efficiency of solar cell, $\eta = \frac{P_{Out}}{P_{In}}$

Where P_{out} is the output electrical power (maximum power point).

P_{in} is calculated by multiplying approximated irradiance ("irradiance" means radiant power of the light incident per unit area) by the effective area of the solar cell on the panel.

This method used the fact that the practical value of the current (maximum photoelectric current measured) is proportional to the photons (radiation) striking the solar cell. This current is therefore proportional to the incident radiant power of the light.

The open circuit voltage depends on the semiconductor material of which solar cell is made. It is not proportional to the incident radiant power and therefore cannot be used for this measurement.

Efficiency of solar cell, $\eta = \frac{P_{Out}}{P_{In}}$

Where P_{out} (Output Electrical Power) = Maximum Power Point (MPP)

P_{in} (Incident radiant power) = Approximated Irradiance \times Area of solar cell

= $F \times I_p \times A$, Here A = Area of a solar cell (Length \times Breadth) m^2

I_p = Practical value of current (maximum photoelectric current measured) indicated on the ammeter,

F is a constant and is given by the ratio of maximum solar irradiance as specified by manufacturer to the maximum value of current.

The maximum irradiance in summer is approx. 1000 W/m^2 (or the power of the source used).. The maximum value of the current specified by the manufacturer is achieved at this value i.e. 150 mA in the given solar cells. (The parameters of the solar cell/panel are related to the standard test conditions of 1000 W/m^2 and cell temperature of 25° C .)

$$F = \frac{1000 \text{ W/m}^2}{150 \text{ mA}}$$

$$F = 6.67 \frac{\text{W}}{\text{m}^2 \cdot \text{mA}}$$

Multiplying the practical value of current (I_p) indicated on the ammeter by the factor gives an approximation of the radiant power per unit area (irradiance) striking the solar cell.

$$F = 6.67 \frac{\text{W}}{\text{m}^2 \cdot \text{mA}}$$

The efficiencies of solar cells lie between 12 to 15 %. If efficiency is slightly less than determined value, then it is due to measuring errors and inaccuracies in determining the incident radiant power. Furthermore, the efficiency of solar panel is less than that of their separate constituent cells. This is caused by losses that arise in matching solar cells that do not all have exactly the same properties. If the solar cells are connected in series to generate desired voltage, the maximum power point may not be same for all cells. Solar cell losses arise as not all photons striking the solar cell can be converted into charge carriers. Part of the light is reflected as soon as it hits the surface and the metal contacts cast shadows. Since the photon energy does not correspond to the energy gap, less than half of the incident energy is used. Recombination of charge carriers (atomic rebanding of electrons) and electrical losses caused by internal resistances (ohmic losses in the semiconductor) of the solar cell and its contacts also arise.

10.9 Result:

The efficiency of the given Solar Cell is%

10.10 Precaution and source of error:

1. Do not make inter connections on the board with mains switched ON.
2. All the connections should be tight.
3. Switch off after taking the readings.

10.11 Summary:

1. The photovoltaic effect is a process to convert light energy into electrical energy in a solar cell when it is exposed to light.
2. Photons in sunlight absorbed by loosely bound electrons in silicon atoms of solar cell and knocked loose flow through the material to produce electricity.
3. The complementary positive charges that are also created (like bubbles) are called holes and flow in the direction opposite of the electrons in a silicon solar panel
4. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity which can also recharge the batteries.

5. Fill factor is the ratio of maximum useful power to ideal power. Maximum useful power is the area of largest rectangle that can be formed under V-I curve.
6. The efficiency of the solar cell is the ratio of produced electrical power (P_{out}) and the
7. incident radiant power (P_{in}).

$$\text{Efficiency of solar cell, } \eta = \frac{P_{out}}{P_{in}}$$

10.12 Glossary:

Photovoltaic effect: generation of electric current in a material upon exposure of light.

Photon: quanta (bundle of energy) of light.

Efficiency: the rate of performance of Solar cell.

Fill Factor: Maximum useful power is the area of largest rectangle under V-I curve

10.13 References:

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi
2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi
3. Indu Prakash, Ram Krishna, A. K. Jha, *A text Book of Practical Physics*, Kitab Mahal Publication Delhi.
4. <https://en.wikipedia.org>
5. *Lab manuals @NISER 2017 Dec*

10.14 Viva-voce questions:

1. What is solar cell?

Ans: A solar cell is an optoelectric device that converts the light energy directly into electricity.

2. Why solar cell is also called photovoltaic cell?

Ans: Solar cell is also called photovoltaic cell because it works in the principle of photovoltaic effect

3. What are the uses of solar cell?

Ans: Solar cells can be used in many ways. They are very economical and reliable way of powering objects. Solar cells are also found very useful in powering spacecrafts, satellites and their inbuilt devices.

4. What do you mean photoelectric effect?

Ans: When an electromagnetic wave of suitable frequency allowed to fall on the metal surface,

electrons may emit. These electrons are known as photoelectrons and the phenomenon is known as photoelectric effect.

5. Define the efficiency of Solar Cell?

Ans: The efficiency of the solar cell is the ratio of produced electrical power (P_{out}) and the

1. incident radiant power (P_{in}).

$$\text{Efficiency of solar cell, } \eta = \frac{P_{out}}{P_{in}}$$

The maximum efficiency achieved so far for solar cell is not more than 17% under specific conditions. Research is still going on to improve the efficiency received from the solar cell.

6. How does temperature effect efficiency of solar cell/photo voltaic cell.

Ans: This change in temperature affects the voltage, power, and efficiency of the cell. The rise in the cell temperature reduces the output of these parameters.

7. Define a fill factor of a photo voltaic cell.

Ans: Fill factor is the ratio of maximum useful power to ideal power. Maximum useful power is the area of largest rectangle that can be formed under V-I curve.

$$\text{Fill factor} = (\text{Maximum useful power} / \text{ideal power})$$

Experiment 11: Stefan's constant

Structure

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- 11.14 References
- 11.15 Viva-voce questions and Answers

11.1 Objectives:

After performing this experiment, you should be able to

- what is meant by a black body
- describe Stefan's law
- understand the power P radiated by the body at absolute temperature T of surrounding

- understand the resistance of conductor depends on temperature 't'
- verify Stefan's law experimentally
- determine Stefan's constant

11.2 Introduction:

The Stefan–Boltzmann law describes the power radiated from a black body in terms of its temperature. Specifically, the Stefan–Boltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time, is directly proportional to the fourth power of the black body's absolute temperature T . The constant of proportionality σ , called the Stefan–Boltzmann constant.

A body that does not absorb all incident radiation (sometimes known as a grey body) emits less total energy than a black body and is characterized by an emissivity. To find the total power radiated from an object, multiply by its surface area.

11.3 Apparatus Used:

Vacuum tube diode (EZ-81), Ammeter, Voltmeter, current source.

11.4 Theory and formula used:

A black body is a substance which emits all radiation falls on it, of whatever wavelength they may be it. The emitted radiation by black body is independent of nature of substance and it purely depends on the temperature of the body.

According to Stefan's law the rate of emission of radiant energy by unit area of perfectly black body is directly proportional to the fourth power of its absolute temperature.

$$\text{So} \quad E = \sigma T^4 \quad (1)$$

where E is net amount of radiant energy per second per unit area by the body at absolute temperature T . σ is Stefan's constant

If the black body at absolute temperature T is surrounded by another black body at absolute temperature T_0 . The body will radiate at absolute temperature T and absorbed radiation at absolute temperature T_0 . So the Stefan's law is

$$E = \sigma(T^4 - T_0^4) \quad (2)$$

A similar relation in equation (2) can also hold for the bodies which are not black bodies. In such case we can write

$$P = C(T^\alpha - T_0^\alpha) \quad (3)$$

$$\text{Where } C = \epsilon S \sigma$$

Where P is power radiated by the body at absolute temperature, α is the exponent of absolute temperature has a value 4 theoretically. T is surrounded by another black body at absolute temperature T_0 . ϵ is emissivity of the material of the cathode, S is the surface area of cathode and σ is the Stefan's constant.

If $T \gg T_0$, the relation is $P = CT^\alpha$

$$\text{Or} \quad \log_{10} P = \alpha \log_{10} T + \log_{10} C \quad (4)$$

Thus the graph between $\log_{10}P$ and $\log_{10}T$ should be straight line whose slope is α , which should close to 4. The intercept will be used to calculate C and hence Stefan's constant (σ).

Assuming conduction and convection power loss is negligible, then power (P) radiated by a hot surface certainly depends on the absolute temperature of the surface as follows:

$$P = CT^\alpha \text{ (where T is the absolute temperature)} \dots\dots\dots(1)$$

$$\text{Or, } \log P = \log C + \alpha \log T \dots\dots\dots(2)$$

$$C = \epsilon S \sigma \dots\dots\dots(3)$$

Where ϵ , the emissivity of the material of cathode, is less than unity because it is not a black body.

S is surface area of cathode = $2\pi r l$ (r is the radius of cylindrical cathode & l the length of cathode).

σ is Stefan's constant which is independent of the material used.

Cathode is heated by passing electric current through the tungsten heater filament. Temperature of the filament can be determined using known resistance (R), temperature(T) relationship for tungsten. Since the cathode sleeve and the heater filament are in close physical contact, we can take the temperature of the cathode to be the same as that of the filament.

Thus the operating temperature of the filament can be determined from measurement of the electrical resistance of the filament. Power radiated and hence resistance can be found out as:

Once the resistance is calculated it is convenient to use graph drawn T vs (R_T/R_{300}) for determination of filament temperature. This graph can be drawn using data of Table 1 available for ready reference for a tungsten filament.

11.5 About apparatus:

EZ-81 is a commercially available diode In which has a cylindrical cathode made of Nickel.

A tungsten heater filament is closely fitted inside the cathode sleeve. The outer surface of the Nickel cathode is coated with BaO and SrO mixture from which thermionic emission takes place.

11.6 Procedure:

Let us perform the experiment in following steps.

1. Put the voltmeter range switch at $1.2 V$ or $1.0 V$ position and the voltage control knob (Marked control VF) at minimum i.e. at the extreme left position.
2. Make connection as shown in figure 1.
3. Connect the set-up to the main's and switch 'ON'.
4. Apply some filament voltage (V_f) say 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0..... 5 V to the filament and measure the corresponding filament current (I_f) in the ammeter displayed during steady-state condition.
5. For steady state condition the time difference between each reading of (V_f) should be about 20 to 30 sec. minimum.

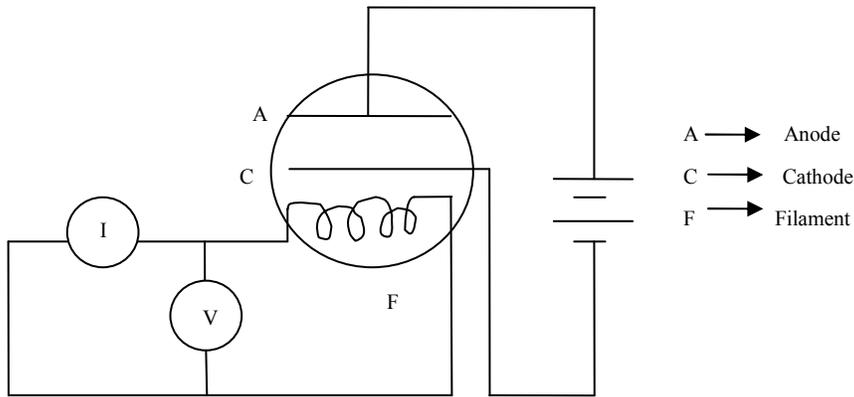


Fig 1: Circuit diagram for Stefan's constant

11.7 Observation

Given constants for Vacuum tube diode EZ-81

1. $R_{300} = 0.6\Omega$
2. Emissivity (ϵ) = 0.24
3. Radius of cathode = 0.12 cm
4. Length of cathode = 3.12 cm
5. Surface area of cathode = 2.42 cm².

Table 2. Determination of power dissipated P for different temperature T of cathode.

S.N	Voltage V_f (In volt)	Current I_f (amp.)	Resistance $R_T = V_f / I_f$ (In ohm)	$R_T / R_{300} = R_T / 0.6$	Temperature T from graph in K given in table2	$\log_{10} T$	Power $P = V_f I_f$	$\log_{10} P$
1								
2								
3								
4								

11.8 Calculation and Discussion:

The relation between power and temperature of tungsten filament is given by

$$\log_{10} P = \alpha \log_{10} T + \log_{10} C$$

So the graph between $\log_{10} P$ and $\log_{10} T$ as shown in Figure 2 is straight line and slope of the straight line should be close 4.

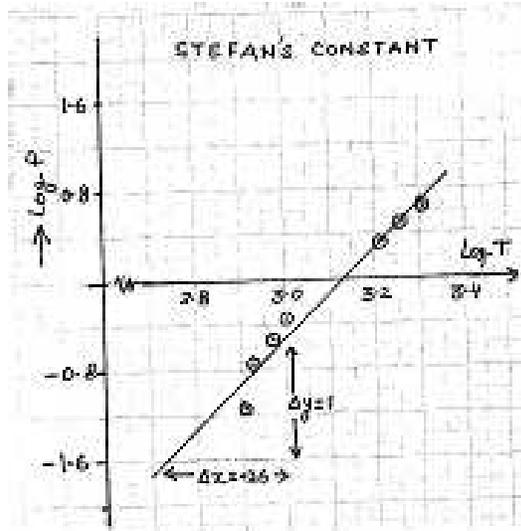


Figure 2: Variation between $\log_{10}P$ and $\log_{10}T$.

Read X-intercept directly. Calculate Y- intercept as $Y_{intercept} = X_{intercept} \times slope$. This $Y_{intercept}$ is equivalent to $\log_{10}C$. From which Stefan's law can be calculated using simple calculations.

11.9 Result:

1. The slope of line of the graph between $\log_{10}P$ and $\log_{10}T$ is straight line and slope of the straight line comes out Hence Stefan's law is verified.
2. The value of Stefan's constant = $Wm^{-2}K^4$.

11.10 Precaution and source of error:

8. The voltage and current should be measured when steady state is obtained.
9. There should not be any fluctuation on the power.
10. Temperature corresponding to the value of R_T/R_{300} from the graph should be taken carefully.

11.11 Required Table and graph:

Table 3: Variation of the temperature with R_T/R_{300} for given Nickel cathode filament.

S.No.	R_T/R_{300}	Temperature in $^{\circ}K$
1	1	300
2	4	920
3	6	1300
4	8	1645
5	10	1990

11.12 Summary:

1. A black body is a substance which emits all radiation falls on it, of whatever wavelength they may be it. The emitted radiation by black body is independent of nature of substance and it purely depends on the temperature of the body.
2. According to Stefan's law, $E = \sigma T^4$

3. If P is power radiated by the body at absolute temperature T is surrounded by another black body at absolute temperature T_0 then

$$\log_{10} P = \alpha \log_{10} T + \log_{10} C$$

4. The resistance R_T of a conductor depends on temperature ' T ' as

$$R_T = R_0(1 + \alpha T + \beta T^2)$$

where temperature coefficients α & β are known for tungsten filament and the resistance of cathode filament at 0°C .

The resistance R_{300} of a conductor depends on temperature ' 300°K ' as

$$R_{300} = R_0(1 + \alpha(300) + \beta(300)^2)$$

So by calculating $\frac{R_T}{R_{300}}$, the temperature of cathode filament can be found.

5. After getting temperature and power P we can make a graph and if this graph comes out a straight line, the Stefan's law is verified.

6. By knowing the value of intercept, Stefan's law can be calculated as per given procedure.

11.13 Glossary:

Black body: a substance which emits all radiation falls on it.

Radiant energy: energy of electromagnetic radiation emitted by a body .

Resistance: the difficulty to pass an electric current through that conductor.

Absolute temperature: 0 K or -273°C .

Filament: a conducting wire or thread with a high melting point, forming part of an electric bulb.

11.14 References:

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi
2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi
3. Indu Prakash, Ram Krishna, A. K. Jha, *A text Book of Practical Physics*, Kitab Mahal Publication Delhi.
4. <https://en.wikipedia.org>
5. *Lab Manual, Physics Laboratory, IIT Roorkee.*

11.15 Viva-voce questions:

1. What is a black body?

Ans: A body which absorbs all incident radiations, irrespective of frequency, is called a black body.

2. State Stefan's law?

Ans.: According to Stefan's law the rate of emission of radiant energy by unit area of perfectly black body is directly proportional to the fourth power of its absolute temperature.

i.e.
$$E = \sigma T^4$$

3. What is a R_T ?

Ans. R_T is resistance of tungsten filament at given absolute temperature.

4. In the experiment how resistance of filament 300°K ?

Ans: The resistance R_{300} of a conductor depends on temperature ' 300°K ' as

$$R_{300} = R_0 (1 + \alpha(300) + \beta(300)^2)$$

Experiment 12: Fresnel's Biprism

Structure

- 12.1 Objectives
- 12.2 Introduction
- 12.3 Apparatus Used
- 12.4 Theory and Formula Used
- 12.5 About apparatus
- 12.6 Procedure
- 12.7 Observation
- 12.8 Calculation and Discussion
- 12.9 Result
- 12.10 Precaution and source of error
- 12.11 Summary
- 12.12 Glossary
- 12.13 References
- 12.14 Viva-voce questions and Answers

12.1 Objectives:

After performing this experiment, you should be able to

- understand the phenomenon of interference
- determine the wavelength of monochromatic light source

12.2 Introduction:

A Fresnel's Biprism is made up of two right angle prisms joined base to base such that the obtuse angle is 178 degree or 179 degree and acute angles are 1 degree or half degree. Due to deviation property of prism, this biprism is able to form two coherent sources from a single source. These coherent sources are virtual or imaginary in nature. This experiment falls in the category of division of wavefront method and produce sustained interference pattern between two coherent light waves of same frequency and having a definite phase relationship. These two virtual sources behave as similar as the real sources formed in Young's double slit method and the position of a particular fringe with its fringe width also holds similar formula as in double slit method.

12.3 Apparatus Used:

Source light, Fresnel's biprism, convex lens, Optical bench with uprights, slit and micrometer eye piece fitted on the optical bench.

12.4 Theory and formula used:

The formation of interference pattern with the help of Fresnel's biprism is shown in Fig. (1). S is source of monochromatic light. Light waves originated from S are allowed to fall on the biprism. Light waves falls on the upper half of the prism and is deviated towards the base and light waves falls on the lower half deviates towards the top. These deviated light waves appear to come from S_1 and S_2 , known as virtual but coherent sources. The waves from two sources combine and give interference pattern and straight fringes are appeared in the focal plane of eyepiece.

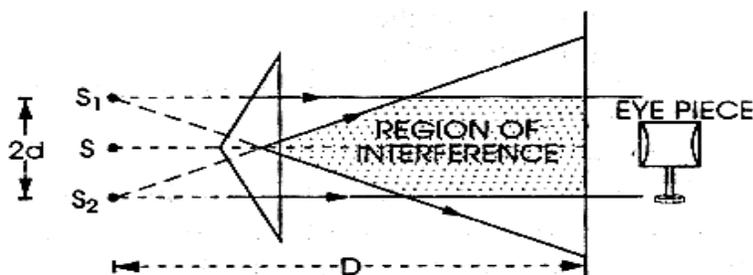


Fig 1: Formation of interference pattern with the help of Fresnel's biprism

The fringe width (β) is given by the formula in the case of Bi-prism experiment.

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

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

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

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

12.5 About apparatus:

This apparatus is used to understand the interference phenomena due to two virtual and coherent sources formed from a single source with the help of Fresnel's biprism. The waves coming out from these sources produce interference pattern on the screen or eyepiece fitted in telescope. A Bi-prism may be regarded as made up of two prisms of very small refracting angles placed base to base. Such biprism can be designed by grinding and polishing a single glass plate to obtain a single prism of obtuse angle 178° or 179° with two acute angles of 1° or $30'$ each.

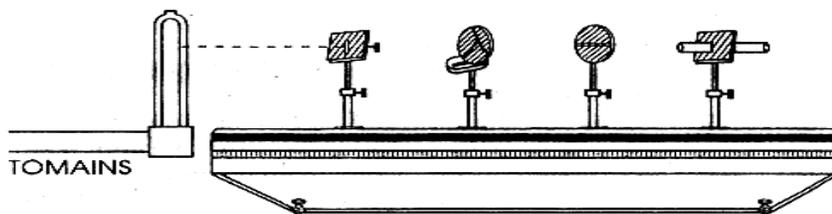


Figure (2): Fresnel's biprism experimental setup

12.6 Procedure:

Let us perform the experiment in following steps.

1. First of all, level the optical bench with the help leveling screws and spirit level.
2. The eye piece, Bi-prism and vertical slit are adjusted at the same level height.
3. The micrometer eye piece is focused on vertical crosswire.

4. The light is allowed to incident on the slit and the optical bench is so adjusted that light comes straight along its lengths.
5. Place the Fresnel's biprism upright near the slit and move the eye piece sideway. See the two images of the slit through biprism; if they are not seen, move the upright of biprism right angle to the bench till they are obtained. Make the two images parallel by rotating biprism in its own plane.
6. Bring the eyepiece near to the Fresnel's biprism and give it a rotation at right angle of the bench to obtain a patch of light. As a matter of fact, the interference fringes are obtained in this patch provided that the edge of the prism is parallel to the slit.
7. To make the edge of the Fresnel's biprism parallel to the slit, the Bi-prism is rotated with the help of tangent screw till a clear interference pattern is obtained. These fringes can be easily seen even with the naked eye.

MESUREMENTS:

(A) MEASUREMENT OF FRINGE WIDTH (β) :

1. Find out the least count of the micrometer screw.
2. Place the micrometer screw at such a distance where fringes are distinct, bright and widely spaced, (say 100 cm.)
3. The crosswire is moved only on one side of the fringes to avoid backlash error. Now the cross wire is fixed at the centre of a bright fringe and its reading is noted on the main scale as well as on micrometer screw.
4. The crosswire is now moved and fixed at the centre of every second bright fringe. The micrometer readings are noted. From these observations β can be calculated.

(B) MEASUREMENT OF D:

The distance between slit and eyepiece uprights (D) is noted with the help of meter scale. The value of D is corrected for the bench error.

(C) MEASUREMENT OF 2d:

The distance 2d between the two virtual sources can be measured with the help of displacement method using convex lens.

1. To obtain the value of $2d$, the positions of slit and Bi-prism uprights are not disturbed.
2. The convex lens is placed between Fresnel's biprism and telescope (eye-piece) and adjusted for obtaining two sharp and focused images of the virtual sources. The distance between two images is noted, which is d_1 (Fig (3)).
3. The lens is again moved towards telescope (eyepiece) for obtaining two sharp and focused images. This second position of the lens is the conjugate position of the first position. The distance in this case is denoted by d_2 .
4. Now, the separation between virtual sources ($2d$) can be calculated by using the formula

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

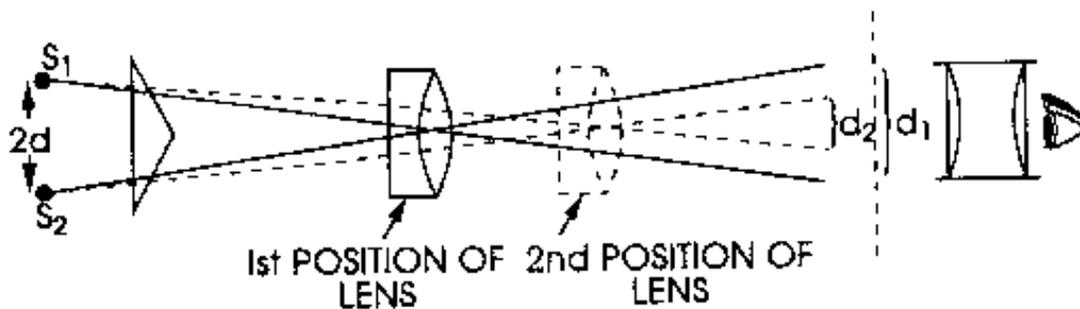


Fig (3): Displacement method to obtain $2d$

12.7 Observation

6. Pitch of the screw = cm.
7. No. of divisions on the micrometer screw = cm.
8. L.C. of micrometer screw = cm.

Table 1. Determination of fringe width

No. of fringes	Micrometer reading(a)			No. of fringes	Micrometer reading (b)			Difference for 10 fringes (a - b)	Mean for 10 fringes	Fringe width β (cm)
	M.S. readin	V.C readin	Total (cm)		M.S. reading	V.C reading	Total (cm)			

	g (cm)	g			(cm)					
1	11	...	...	...	...
3	13	...	...	...	...
5	15	...	...	...	...	...	...
7	17	...	...	...	...
9	19	...	...	...	...

MEASUREMENT OF D:

Position of upright carrying list = cm.

Position of upright carrying the eyepiece = cm.

Observed value of D = cm.

MEASUREMENT OF 2d:

S.No.	Micrometer reading						$2d = \sqrt{(d_1 d_2)}$	Mean 2d
	I st position of lens			2 nd position of lens				
	I image	II image	d ₁	I image	II image	d ₂		
1.
2.
3.

12.8 Calculation and Discussion:

The wavelength of the given source light can be calculated as

$$\lambda = \beta \frac{2d}{D} = \dots \text{A}^0$$

12.9 Result:

The wavelength of the given light is = A⁰

12.10 Precaution and source of error:

11. All uprights should be set at the same level.
12. A vertical and narrow slit should be used.
13. Removal of fringe shift is essential.
14. All bench errors should be considered.
15. Observations for fringe width are taken with positioning the crosswire should in the centre of the fringe.
16. To avoid backlash error, micrometer screw should be rotated only either clockwise or anticlockwise.
17. The focal length of the convex lens should be short (f = 25 cm. approx.).

12.11 Summary:

1. A biprism consist of two right angled prisms with their bases in contact such that the obtuse angle is either 178 or 179 degree
2. It forms two virtual sources due to deviation property of prism.
3. The fringe width of fringe pattern formed due to interference in Fresnel's biprism is given by

$$\text{Fringe width} = \lambda \frac{D}{2d}$$

Where, λ is the wavelength of source light, D is the distance between source and screen and 2d is the distance between two virtual sources.

4. The distance (D) is measured with the help of meter scale and fringe width is measured with the help of micrometer placed in telescope and eyepiece.
5. The separation of two virtual and coherent sources are obtained with the help of convex lens applying displacement method. If d_1 and d_2 are found the separation between the two images of separation between virtual sources (2d) for two conjugate positions of convex lens, the following formula gives 2d

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

6. By knowing the value of D, 2d and fringe width, wavelength of the monochromatic light from the source can be calculated as per given formula.

12.12 Glossary:

Coherent sources: two sources which can emit waves in same phases.

Virtual sources: the sources with no physical existence but behave like real sources.

Crosswire: used with telescope and micrometer to locate exact position of a fringe.

Monochromatic light source: A source which emits light wave of single frequency.

12.13 References:

1. C. L. Arora, *B.Sc. Practical Physics*, S. Chand publication, Delhi
2. C.L. Arora and P.S. Hemne, *Physics for Degree students (BSc Second year)*, S. Chand publication, Delhi
3. Indu Prakash, Ram Krishna, A. K. Jha, *A text Book of Practical Physics*, Kitab Mahal Publication Delhi.
4. <https://en.wikipedia.org>

12.14 Viva-voce questions:

1. What do you mean by monochromatic light?

Ans: A monochromatic light has single wavelength or frequency.

2. What is Bi-prism?

Ans: A Fresnel's Biprism is made up of two right angle prisms joined base to base such that the obtuse angle is 178 degree or 179 degree and acute angles are 1 degree or half degree. It is used to produce two coherent sources from a single source.

3. What are coherent sources?

Ans. Coherent sources are the sources which produces waves of same frequency and in same phase.

4. Is it possible to observe interference fringes with light coming from two independent lamps or candles?

Ans: No, because two independent lamps or candles cannot act as coherent sources which is a necessary condition for interference.

5. What do you mean by interference of light? How many types of interferences have you read?

Ans: Interference is the redistribution of energies of the two wave fronts superimposing on each other. The resultant energy is non-uniformly distributed in the form of bright and dark fringes. Interference are classified into two types based on the formation of coherent sources from a single source. These are division of wavefront and division of amplitude.

EXPERIMENT 13: THE FABRY-PEROT INTERFEROMETER

Structure

- 13.1 Objectives
- 13.2 Introduction
- 13.3 Apparatus Used
- 13.4 Theory and Formula Used
- 13.5 About apparatus
- 13.6 Procedure
- 13.7 Observation
- 13.8 Calculation and Discussion
- 13.9 Result
- 13.10 Standard Result
- 13.11 Percentage error
- 13.12 Precaution and source of error
- 13.13 Viva-voce questions and Answers
- 13.14 References

13.1 OBJECTIVES:

After performing this experiment, you should be able to understand

- What is Fabry-Perot Etalon
- Theory of multiple reflection from a plane parallel film
- Variation of transmittivity as a function of δ (phase difference) for different values of F (finesse).
- Adjustment of the experimental arrangement of the Fabry-Perot Interferometer.
- How to determine the separation between the plates of a Fabry-Perot Etalon?
- Alignment of Fabry-Perot Interferometer to observe concentric circular fringes.
- Measurement of the wavelength of a diode Laser

13.2 INTRODUCTION:

It is a high resolving power instrument which makes use of fringes of constant inclination produced by the transmitted light after multiple reflections in an air film between two parallel highly reflecting glass plates. The Fabry-Perot interferometer, simply referred to as the Fabry-Perot Etalon, is an important application of multiple wave interference in optics. It consists of two partially reflecting surfaces aligned with each other in such a way that many waves of light derived from the same incident wave can interfere. The resulting interference patterns may be used to analyze the spectral character of the incident beam.

13.3 APPARATUS USED:

Fabry-Perot Etalon, spectrometer, condensing lens, reading lamp, sodium lamp

13.4 THEORY AND FORMULA USED:

The condition of Maxima in Fabry-Perot interferometer is given by

$$2d \cos \Theta = n \lambda \text{ or } d = \frac{n \lambda}{2 \cos \Theta}$$

Where d = separation between the plates, n = order of interference, Θ = angle of incidence, λ = wavelength of light used (589 nm for sodium light). For the details, we can understand further sections in brief.

13.4.1. *The Fabry –Perot Interferometer*

It is a high resolving power instrument which makes use of fringes of constant inclination produced by the transmitted light after multiple reflections in an air film between two parallel highly reflecting glass plates. The Fabry-Perot interferometer, simply referred to as the Fabry-Perot Etalon, is an important application of multiple wave interference in optics. It consists of two partially reflecting surfaces aligned with each other in such a way that many waves of light derived from the same incident wave can interfere. The resulting interference patterns may be used to analyze the spectral character of the incident beam.

13.4.2. *Fabry-Perot Etalon*

An etalon is an optical interferometer that consists of two optically plane glass plates with their inner surfaces silvered, separated by a small, fixed distance and placed accurately parallel to each other. A beam of light undergoes multiple reflections between the surfaces of the glass plates fig. 13.1. This results in optical transmission (or reflection) that is periodic in wavelength. This creates an image of many fringes. A sodium lamp or diode laser is used as a light source, and the interference produced by the etalon is recorded.

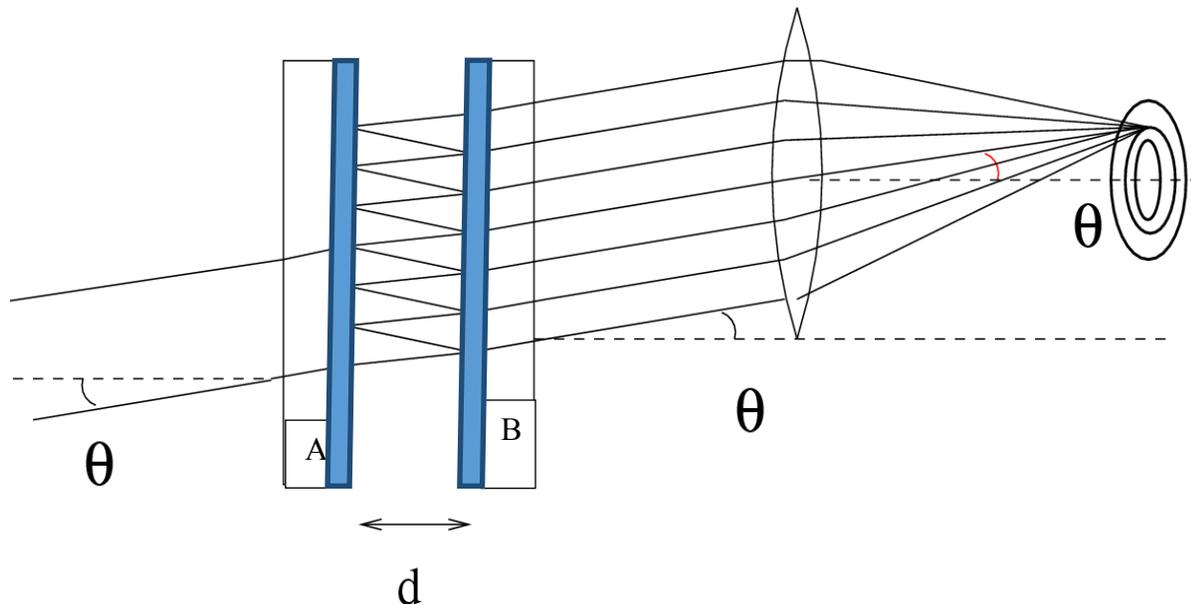


Fig 13.1 The Fabry-Perot Interferometer consists of two optically plain glass plates A and B with their inner surface is silvered, and placed accurately parallel to each other. Screws are provided to secure parallelism if disturbed. The plates themselves are slightly prismatic to avoid interference among the rays reflected at the outer non silvered surfaces.

13.4.3. Multiple Reflection from Parallel Film (Fabry-Perot Etalon)

A beam of light undergoes multiple reflections between the surfaces of the glass plates. We consider the incidence of a plane wave on a plate of thickness d (and of refractive index $n_2 = \mu$) surrounded by a medium of refractive index $n_1 = 1$ (for air) as shown in Fig. 13.2 (a).

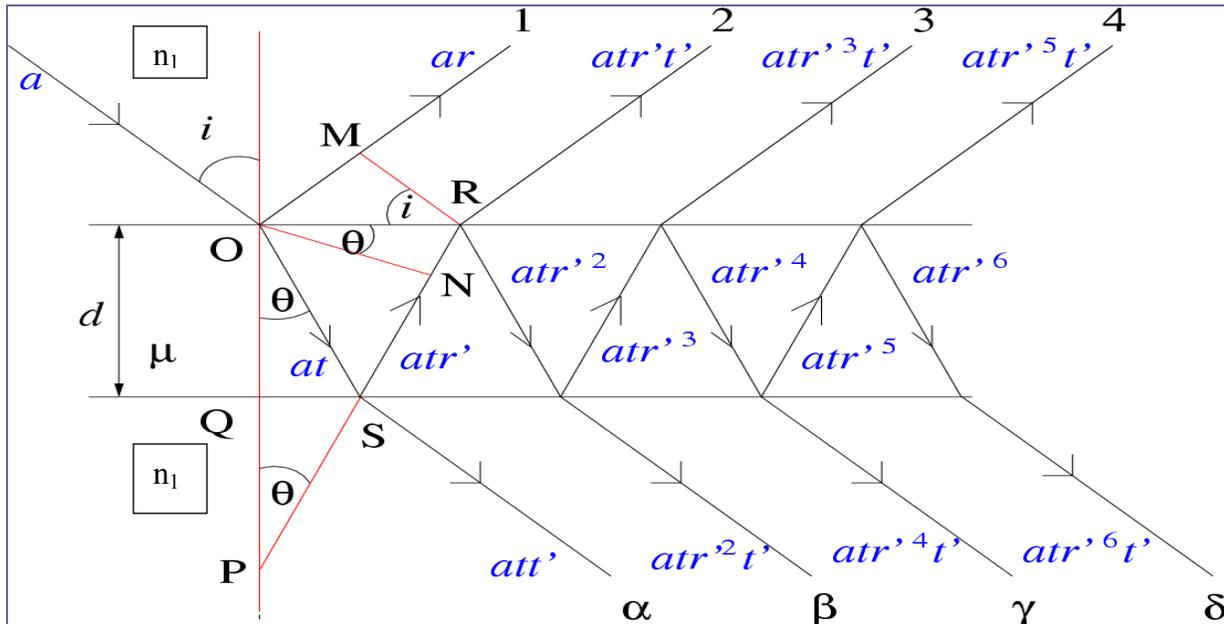


Fig. 13.2(a) Reflection and transmission of a beam of amplitude a_0 incident at an angle i on a film of refractive index μ and thickness d .

Let a_0 be the (complex) amplitude of the incident wave. The wave will undergo multiple reflections at the two interfaces as shown in Fig. 13.2(a). Let r and t represent the amplitude reflection and transmission coefficients, respectively, when the wave is incident from n_1 toward n_2 , and let r' and t' represent the corresponding coefficients when the wave is incident from n_2 toward n_1 . Path difference between rays 2 and 1 will be $(OS + SR \text{ in film}) - (OM \text{ in air})$, which is $\Delta = 2 \mu d \cos \theta$. Thus the amplitude of the successive reflected waves will be $a_0 r$, $a_0 t r' t' e^{i\delta}$, $a_0 t t' r' e^{3i\delta}$, $a_0 t t' r' e^{5i\delta}$, ... respectively. Similarly, the amplitude of the successive transmitted waves will be $a_0 t t'$, $a_0 t r' t' e^{i\delta}$, $a_0 t t' r' e^{2i\delta}$, $a_0 t t' r' e^{3i\delta}$, ... respectively. Where δ is successive phase difference between two rays,

$$\delta = \frac{2\pi}{\lambda} \Delta \quad \text{substituting } \Delta = 2 \mu d \cos \theta \quad \text{we get, } \delta = \frac{4\pi \mu d \cos \theta}{\lambda} \text{ is the phase difference}$$

(between two successive waves emanating from the plate) due to the additional path traversed by the beam in the film and λ is the wavelength.

For Any incident ray parallel to AB as shown in Fig. 13.2 (b) multiple reflections will focus at the same point P. If ray AB is rotated about the normal at B, then point P will rotate on the circumference of a circle centered at point O; this circle will be bright or dark depending on the

value of Θ_i . Rays incident at different angles will focus at different distances from point O. Similarly, multiple transmitted waves will focus at P' will rotate on the circumference of a circle centered at point O' and one will obtain concentric bright and dark rings as in fig. 13.2 (c) for an extended source.

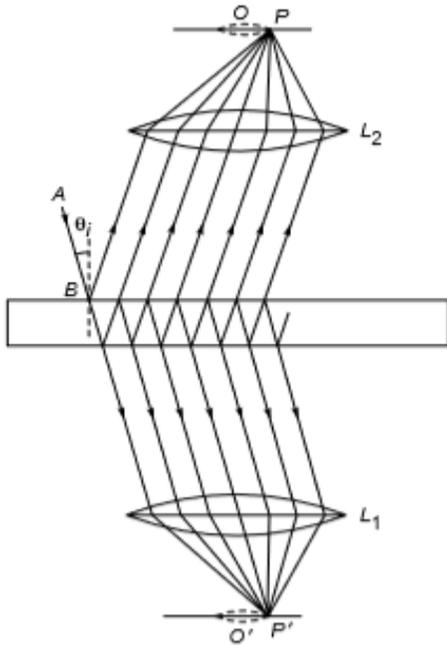


Fig. 13.2 (b)

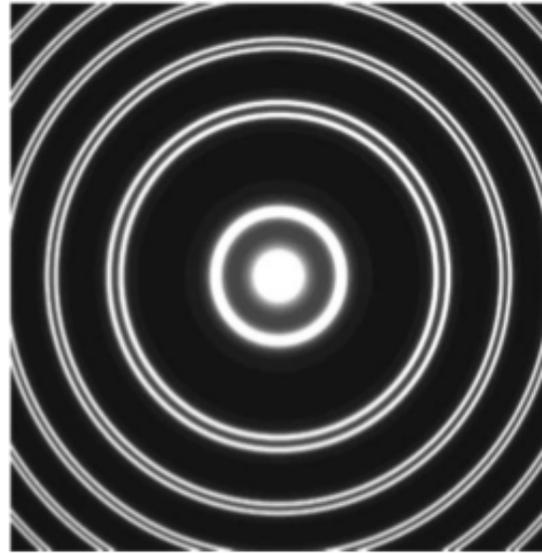


Fig. 13.2 (c)

13.4.4. Resultant Amplitude of Reflected Waves

In this section we will try to find out resultant amplitude of all the successive reflected waves. In section 13.3 we have seen the amplitude of successive reflected waves are $a_0 r$, $a_0 t r' t' e^{i\delta}$, $a_0 t t' r'^3 e^{2i\delta}$, $a_0 t t' r'^5 e^{3i\delta}$, ... respectively. Thus the resultant (complex) amplitude of the reflected wave will be

$$\begin{aligned} A &= a_0 r + a_0 t r' t' e^{i\delta} + a_0 t t' r'^3 e^{2i\delta} + a_0 t t' r'^5 e^{3i\delta} + \dots \\ A &= a_0 [r + t r' t' e^{i\delta} + t t' r'^3 e^{2i\delta} + t t' r'^5 e^{3i\delta} + \dots] \\ A &= a_0 [r + t r' t' e^{i\delta} \{ 1 + r'^2 e^{i\delta} + r'^4 e^{2i\delta} + \dots \}] \end{aligned}$$

Using sum of G.P. series, we can get

$$A = a_0 \left[r + \frac{t t' r' e^{i\delta}}{1 - r'^2 e^{i\delta}} \right] \quad \text{-----} \quad (13.4.1)$$

Now, if the reflectors are lossless, the reflectivity R and the transmittivity τ at each interface are given by

$$r' = -r$$

$$R = r^2 = r'^2$$

$$\tau = t t' = 1 - R$$

Substitute in equation 13.4.1, we get

$$\frac{A}{a_0} = r \left[1 - \frac{(1-R)e^{i\delta}}{1-R e^{i\delta}} \right] \quad \text{-----} \quad (13.4.2)$$

Thus the irradiance reflectivity (the square of ratio of resultant amplitude with incident) of the Fabry-Perot etalon is given by

$$\mathcal{R} = \frac{|A|^2}{|a_0|^2} = r^2 \left| 1 - \frac{(1-R)e^{i\delta}}{1-R e^{i\delta}} \right|^2 = R \left| 1 - \frac{(1-R)e^{i\delta}}{1-R e^{i\delta}} \right|^2$$

$$\mathcal{R} = \frac{|A|^2}{|a_0|^2} = R \left| \frac{1-e^{i\delta}}{1-R e^{i\delta}} \right|^2 = R \left| \frac{(1-\cos\delta)^2 + \sin^2 \delta}{(1-R\cos\delta)^2 + R^2 \sin^2 \delta} \right|$$

$$\mathcal{R} = \frac{4R \sin^2 \delta/2}{(1-R)^2 + 4R \sin^2 \delta/2} \text{ substitute, } F = \frac{4R}{(1-R)^2} \text{ we can get}$$

$$R = \frac{F \sin^2 \delta/2}{1 + F \sin^2 \delta/2} \quad (13.4.3)$$

Where $F = \frac{4R}{(1-R)^2}$ is called the **coefficient of Finesse**. If $R \ll 1$, F is small and the reflectivity is proportional to $\sin^2 \delta/2$. In Fabry-Perot interferometer by increasing reflectivity, the sharpness of the bright rings will increase with the value of F . In the visible region of the spectrum, silver is the best metal to coat with glass plates (the reflectivity is about 0.97 in the red region and decreases to about 0.90 in the blue region). But beyond the blue region, the reflectivity falls rapidly.

13.4.5. Resultant Amplitude of Transmitted Waves

In this section we will try to find out resultant amplitude of all the successive transmitted waves. In section 13.3 we have seen the amplitude of successive transmitted waves are $a_0 t t'$, $a_0 t r'^2 t' e^{i\delta}$, $a_0 t t' r'^4 e^{2i\delta}$, $a_0 t t' r'^6 e^{3i\delta}$, respectively. We have assumed the first transmitted wave to have zero phase. Thus the resultant (complex) amplitude of the transmitted wave will be given by

$$A = a_0 t t' + a_0 t r'^2 t' e^{i\delta} + a_0 t t' r'^4 e^{2i\delta} + a_0 t t' r'^6 e^{3i\delta} + \dots$$

$$A = a_0 t t' [1 + r'^2 e^{i\delta} + r'^4 e^{2i\delta} + r'^6 e^{3i\delta} + \dots]$$

Using sum of G.P. series, we can get

$$A = a_0 \left[\frac{t t'}{1 - r'^2 e^{i\delta}} \right] \quad (13.5.1)$$

If the reflectors are lossless, the reflectivity R and the transmittivity τ at each interface are given by

$$r' = -r$$

$$R = r^2 = r'^2$$

$$\tau = t t' = 1 - R$$

Substitute in equation 13.5.1, we get

$$A = a_0 \left[\frac{1-R}{1 - R e^{i\delta}} \right] \quad (13.5.2)$$

Thus the transmittivity T of the film is given by

$$T = \frac{|A|^2}{|a_0|^2} = \frac{(1-R)^2}{(1 - R e^{i\delta})^2} = \frac{(1-R)^2}{(1 - R \cos \delta)^2 + R^2 \sin^2 \delta}$$

$$T = \frac{(1-R)^2}{(1-R)^2 + 4R \sin^2 \delta/2} \text{ substitute, } F = \frac{4R}{(1-R)^2} \text{ we can get}$$

$$T = \frac{1}{1 + F \sin^2 \delta/2} \quad \text{-----} \quad (13.5.3)$$

It is easily observed that the sum of reflectivity and transmittivity is added up to unity. We can add equation (13.4.3) and (13.5.1) to get $(R + T = 1)$. i.e;

$$R + T = \frac{F \sin^2 \delta/2}{1 + F \sin^2 \delta/2} + \frac{1}{1 + F \sin^2 \delta/2} = 1$$

From equation (13.5.3), the maximum value of T can be 1 when $\sin^2 \delta/2$ tends to minimum.

Further,

$$T = 1 \text{ when } \sin^2 \delta/2 = 0 \text{ or } \delta = 2 m \pi ; \text{ where } m = 1, 2, 3, \dots$$

One can show variation of transmittivity as a function of δ for different values of F . Fig. 13.4 shows the transmittivity of a Fabry–Perot etalon as a function of δ for different values of F . The transmission become much sharper as we increase the value of F .

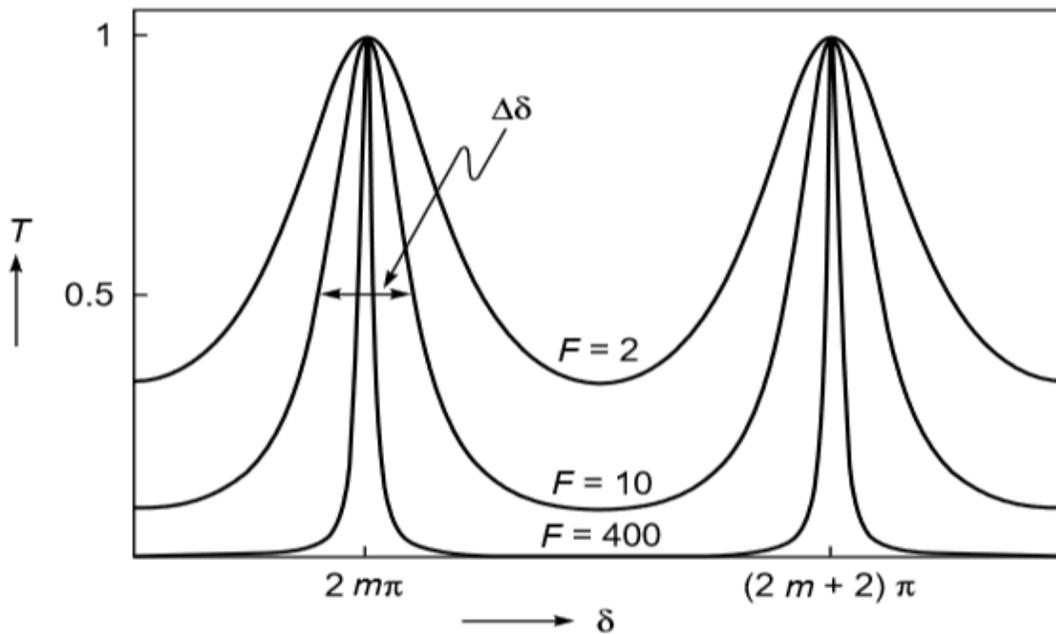


Fig. 13.4. variation of transmittivity as a function of δ for different values of F .

13.4.6. The full width at half maximum (FWHM)

In Fig. 13.4, we have plotted the transmittivity as a function of δ for different values of F , the value of m is usually large. The transmission resonances become sharper as we increase the value of F . The range of δ for which transmittivity is higher than the value of 0.5 (more than the half of maximum) is known as the full width at half maximum (FWHM) and denoted by $\Delta \delta$. To get an estimate of the (FWHM) width of the transmission, let $T = \frac{1}{2}$ substitute the value in equation 13.5.3, we can write

$$\frac{1}{2} = \frac{1}{1 + F \sin^2 \delta/2} \text{ Thus, } F \sin^2 \delta/2 = 1 \text{----- (13.5.4)}$$

Therefore from Fig. 13.5, for FWHM the value of δ should be

$$\delta = 2 m \pi \pm \frac{\Delta \delta}{2} \text{ Thus, } F \sin^2 \Delta \delta/4 = 1 \text{----- (13.5.5)}$$

In almost all cases, $\Delta \delta \ll 1$, and therefore, to a very good approximation, it is given by

$$\Delta \delta = \frac{4}{\sqrt{F}} = \frac{2(1-R)}{\sqrt{R}} \text{----- (13.5.6)}$$

Now two important facts are

- (i) The transmission resources become sharper as the value of F increases,
- (ii) Fig. 13.5 shows that larger the value of R , the more rapid is the fall of intensity on either side of the maximum.

That is, higher the reflectivity of the plates, sharper are the interference bright fringes. With these facts, Marie Fabry and Jean Perot invented the Fabry–Perot interferometer which is characterized by a very high resolving power.

13.5 ABOUT APPARATUS

The experimental arrangement is shown in figure 13.5 (a).

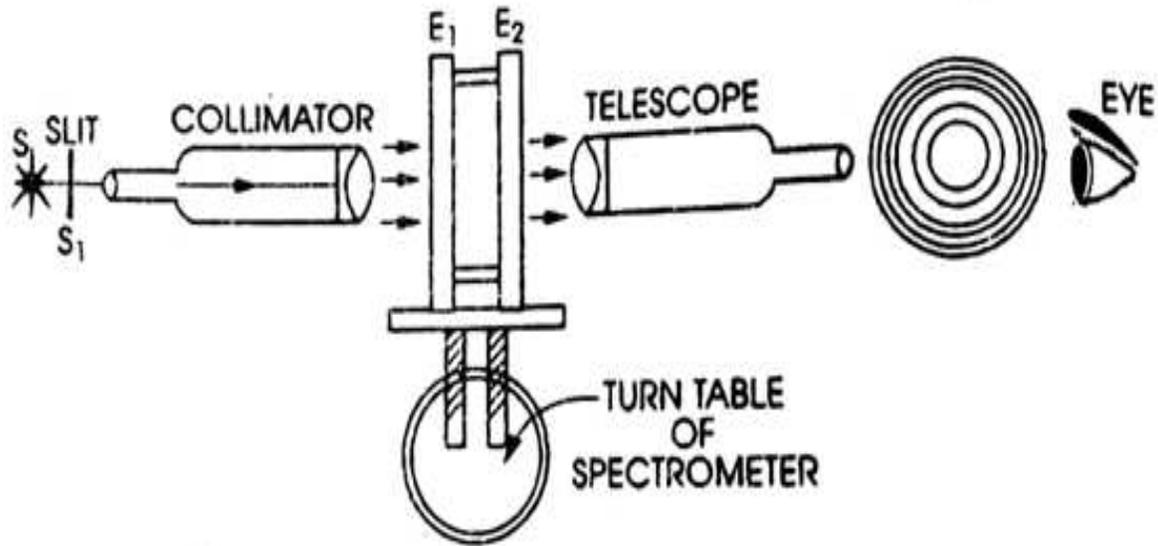


Figure 13.5 (a): Fabry-Perot interferometer Experimental Setup

In figure 13.5 (a), S is a broad source of monochromatic light and S_1 is an adjustable slit. Fabry-Perot Etalon E_1 , E_2 is placed on the turntable of an ordinary spectrometer. The collimator collimates the beam which suffers multiple reflection in the air film of Fabry Perot Etalon. The transmitted light is collected by telescope.

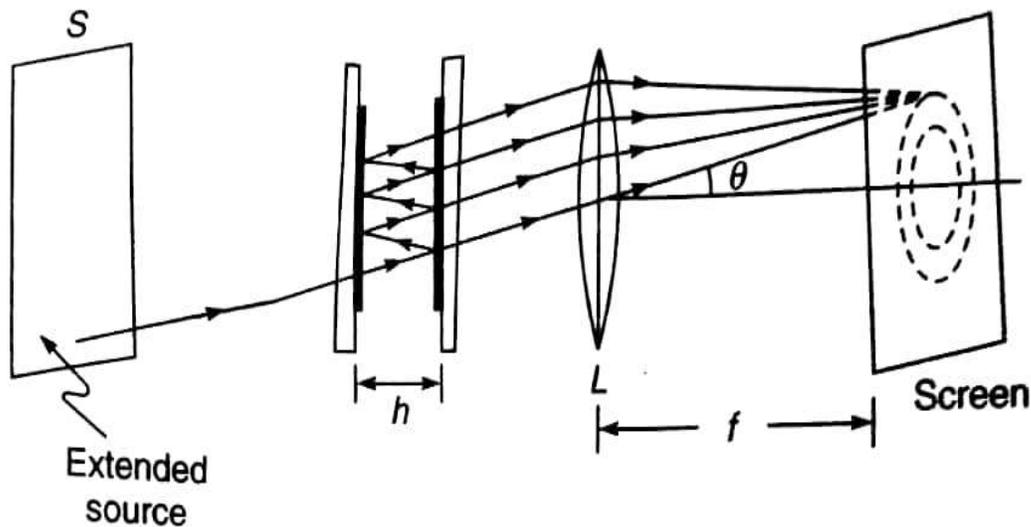


Figure 13.5 (b): Fabry-Perot interferometer formation of ring by multiple reflections.

When viewed through the telescope, circular fringes are observed. Sometimes the fringes are not very clear. To obtain a clear Fringe pattern, the following adjustment is made: The spectrometer

is turned in such a way that light falls directly from the source on the Fabry Perot Etalon i.e., collimator is removed from the light path. An oily paper with a fine pinhole is placed in front of the source. Now circular fringes are clearly observed through telescope.

13.6 PROCEDURE

We have to follow the following steps:

1. First the fringe pattern is brought at the centre of the field of view by adjusting the screws provided at the base of the Italian for leveling.
2. Make an adjustment so that a clear fringes fringe pattern must be observed.
3. The turntable is fixed and the telescope is moved through right of the fringe pattern.
4. The cross wire of the telescope is made tangential to the first dark ring and the turntable reading is noted.
5. By moving the telescope the procedure is repeated for successive dark fringes till the clearly visible fringes (rings) are obtained.
6. Procedure numbers 2 to 5 are repeated toward the left side of fringe (ring) pattern.
7. The angular diameter $2\Theta_n$ of the Rings are measured as shown in the table 1 given in section 13.7.

13.7 OBSERVATION

Table1: Determination of Angular Diameter $2\Theta_n$ and $\cos\Theta_n$

Number of Ring	LCS [#] =, Angular Diameter $2\Theta_n$				Difference	Mean $2\Theta_n$	Θ_n	Cos Θ_n
	Reading on left (l)		Reading on right (r)		(r) - (l)			
	Main scale (a)	Small scale (b)	Main scale (c)	Small scale (d)					$2\Theta_n$

1	....	.....	....	.....	....	....	....	....
2								
3								
4								
.								
.								
20								

#LCS = Least count of spectrometer

13.8 CALCULATION AND DISCUSSION

A graph is plotted between $\text{Cos}\theta_n$ as a function of ring number n . The graph is shown in figure 13.8.

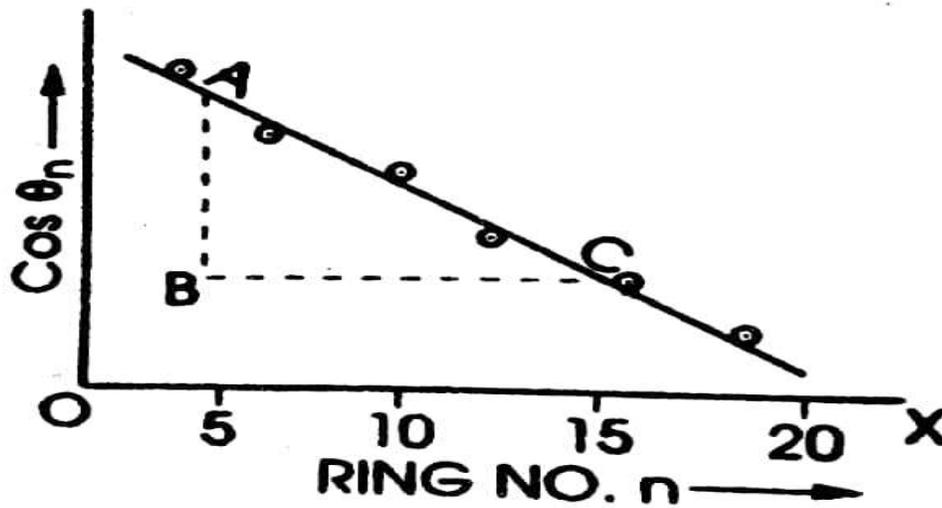


Figure13.8. : Graph between $\text{Cos}\theta_n$ as a function of ring number n .

From the figure 13.8, Graph between $\cos \theta_n$ as a function of ring number n , in triangle ABC,

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

From formula used in section 13.4, the condition of maxima in Fabry-Perot interferometer is given by

$$2d \cos \theta_n = n \lambda \text{ or } d = \frac{n \lambda}{2 \cos \theta_n} = \frac{BC \lambda}{AB 2}$$

Where $d = h$ = separation between the plates, n = order of interference, θ_n = angle of incidence for n^{th} ring, λ = wavelength of light used (589.3 nm for sodium light). Hence the value of d can be calculated.

13.9 RESULT

The thickness of Fabry-Perot Etalon = cm

13.10 STANDARD RESULT

The thickness of Fabry-Perot Etalon is about 1.0 cm. However it may depend on the Etalon available in the laboratory.

13.11 PERCENTAGE ERROR

$$\% \text{ Error} = \frac{|\text{observed value} - \text{standard value}|}{\text{standard value}} \times 100 \%$$

13.12 PRECAUTION AND SOURCE OF ERROR

- The centre of the fringe pattern should be made at the centre of field of view.
- The screw should be handled carefully.
- There should not be linear or lateral displacement of circular fringes when viewed by eye.
- While taking readings the turntable should be fixed.
- Before measuring the diameter of the ring the telescope should be properly adjusted.
- Cross wire should be focused tangentially.
- There should be no disturbance near the experiment setup.
- Reading and graph should be taken carefully.

13.13 VIVA-VOCE QUESTION AND ANSWERS

Question 1: What is Fabry-Perot etalon?

Answer: This is a multiple beam high resolution interferometer designed by fabry and perot.

Question 2: What is the construction of Fabry-Perot etalon?

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

Question 3: What is the shape of fringes?

Answer:The fringes are circular which are widely separated at the center while crowded for larger radii.

Question 4: What is the difference between these fringes and those obtained in Michelson's interferometer?

Answer:These fringes are much more narrower, sharper and brighter than those of Michelson's interferometer.

Question 5: what do you mean by sharpness of fringes?

Answer:The sharpness of fringes defines how rapidly the intensity diminishes on either side of maximum.

Question 7: What is half width of a ring?

Answer:This is the total width of a Fringe at those points where the intensity has fallen to half the maximum intensity?

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EXPERIMENT 14: HALL EFFECT

Structure

- 14.1 Objectives
- 14.2 Introduction
- 14.3 Apparatus Used
- 14.4 Theory and Formula Used
- 14.5 About apparatus
- 14.6 Procedure
- 14.7 Observation
- 14.8 Calculation and Discussion
- 14.9 Result
- 14.10 Standard Result
- 14.11 Percentage error
- 14.12 Precaution and source of error
- 14.13 Viva-voce questions and Answers
- 14.14 References

14.1 OBJECTIVES:

After performing this experiment, you should be able to understand

- What is Hall Effect?
- What is Hall Effect geometry?
- How to produce hall potential along lateral to the direction of flow of current and magnetic field.
- How to determine the sign of the charge carriers, e.g. electron or holes in a semiconductor?
- How to determine their (electron or holes) density in a given sample?
- The Hall Effect is an important diagnostic tool for the characterization of materials – particularly semi-conductors.
- Adjustment of the experimental arrangement of the Hall Effect.
- How to determine Hall voltage, Hall coefficient and the number of charge carriers per unit volume.
- How to determine Hall angle and mobility.

14.2 INTRODUCTION:

In 1879 E. H. Hall observed that when an electrical current passes through a sample placed in a magnetic field, a potential proportional to the current and to the magnetic field is developed across the material in a direction perpendicular to both the current and to the magnetic field. This effect is known as the Hall Effect, and is the basis of many practical applications and devices such as magnetic field measurements, position and motion detectors. With the measurements, Hall was able to determine for the first time the sign of charge carriers in a conductor. Even today, Hall effect measurements continue to be a useful technique for characterizing the electrical transport properties of metals and semiconductors. Indeed, the failure of the simple model of metallic conductivity, which we discuss below, to account for many experimental measurements of the Hall effect has been one of the principal motivators leading to a better understanding of electronic properties of materials. In this experiment, the Hall Effect will be used to study some of the physics of charge transport in metal and semiconductor samples.

14.3 APPARATUS USED:

A rectangular slab of semiconductor crystal of thickness about 0.3 mm, Electromagnet, search coil, calibrated flux meter to measure magnetic field or ballistic Galvanometer, millivolt meter, battery, ammeter and keys.

14.4 THEORY AND FORMULA USED:

Consider a conducting slab as shown in Fig. 14.1 with length l in the x-direction, width w in the y-direction and thickness t in the z-direction.

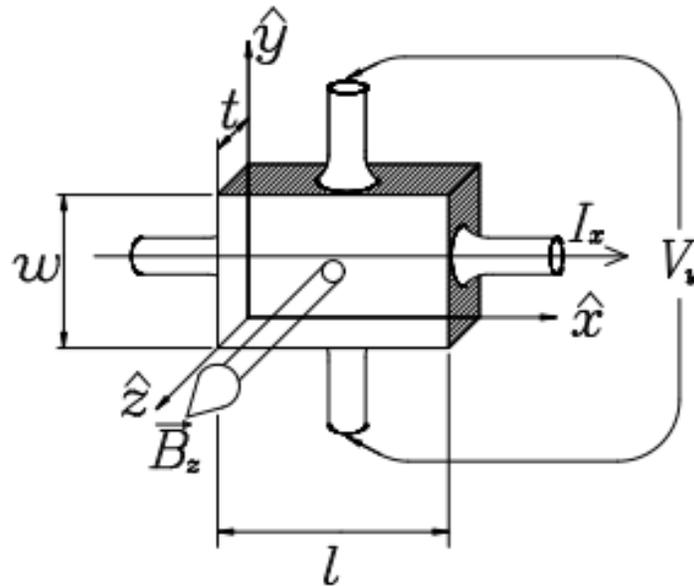


Figure 14.1: Geometry of fields and sample in Hall effect experiment.

Assume the conductor to have charge carrier of charge q (can be either positive or negative or both, but we take it to be of just one sign here), charge carrier number density n (i.e., number of carriers per unit volume), and charge carrier drift velocity v_x when a current I_x flows in the positive x direction. The drift velocity is an average velocity of the charge carriers over the volume of the conductor; each charge carrier may move in a seemingly random way within the conductor, but under the influence of applied fields there will be a net transport of carriers along the length of the conductor. The current I_x is the current density J_x times the cross-sectional area of the conductor wt . The current density J_x is the charge density nq times the drift velocity v_x .

In other words,

$$I_x = J_x wt = nqv_x wt \quad \dots\dots\dots (14.1)$$

The current I_x is caused by the application of an electric field along the length of the conductor E_x . In the case where the current is directly proportional to the field, we say that the material obeys Ohm's law, which may be written

$$J_x = \sigma E_x \quad \dots\dots\dots (14.2)$$

where σ is the conductivity of the material in the conductor. Now assume that the conductor is placed in a magnetic field perpendicular to the plane of the slab. The charge carriers will experience a Lorentz force $q(\mathbf{v} \times \mathbf{B})$ that will deflect them toward one side of the slab. The result of this deflection is to cause an accumulation of charges along one side of the slab which creates a transverse electric field E_y that counteracts the force of the magnetic field. (Recall that the force of an electric field on a charge q is qE .) When steady state is reached, there will be no net

flow of charge in the y direction, since the electrical and magnetic forces on the charge carriers in that direction must be balanced. Assuming these conditions, it is easy to show that

$$E_y = v_x B_z \quad \dots\dots\dots (14.3)$$

where E_y is the electric field, called the Hall field, in the y direction and B_z the magnetic field in the z direction. In an experiment, we measure the potential difference across the sample, called the Hall voltage V_H which is related to the Hall field by

$$V_H = - \int_0^w E_y dy = -E_y w \quad \dots\dots\dots (14.4)$$

Thus, from equations (14.1), (14.3) and (14.4) we obtain

$$V_H = - \left(\frac{1}{nq} \right) \left(\frac{I_x B_z}{t} \right) \dots\dots\dots (14.5)$$

The term in parenthesis is known as the Hall coefficient:

$$R_H = \left(\frac{1}{nq} \right) \quad \dots\dots\dots (14.6)$$

It is positive if the charge carriers are positive, and negative if the charge carriers are negative. In practice, the polarity of V_H determines the sign of the charge carriers. Note that the SI units of the Hall coefficient are $[m^3/C]$ or more commonly stated $[m^3/A-s]$. To measure the Hall coefficient, we can write,

$$R_H = \left(\frac{1}{nq} \right) = - \left(\frac{V_H}{I_x} \right) \cdot \left(\frac{d}{B_z} \right) \cdot 10^4 \text{ meter}^3/\text{coulomb} \dots (14.7)$$

Where V_H is measured in volt, I_x is measured in ampere, thickness $t = d$ is in meter and B_z in gauss. If permeability of the medium of a crystal is μ than actual magnetic field within the crystal is $B_z = \mu B$ (where B is applied magnetic field along z direction). If B_z is measured in weber/meter² then equation 14.7 can be expressed as,

$$R_H = \left(\frac{1}{nq} \right) = - \left(\frac{V_H}{I_x} \right) \cdot \left(\frac{d}{B_z} \right) \text{ meter}^3/\text{coulomb} \dots (14.7)$$

To determine number of charge carriers per unit volume in the semiconductor crystal n (electron concentration in n type semiconductor and hole concentration in p type semiconductor) formula is given by

$$n = \left(\frac{1}{R_H q} \right) (\text{meter})^{-3} \dots (14.8)$$

where $q = 1.6 \times 10^{-19}$ coulomb. To determine Hall angle we can use the formula

$$\Phi = \left(\frac{V_H}{V_x} \right) \cdot \left(\frac{l_x}{w} \right) \text{ rad.} \quad \dots\dots\dots (14.9)$$

Where $w = b$ is the width of crystal along y direction, l_x and width b both are measured in meter.

To determine mobility, we can write the expression

$$m_{\mu} = \left(\frac{\Phi}{B_z} \right) \quad \text{rad. meter}^2/\text{weber} \quad \dots\dots\dots (14.10)$$

14.5 ABOUT APPARATUS:

The experimental arrangement is shown in figure 14.5.

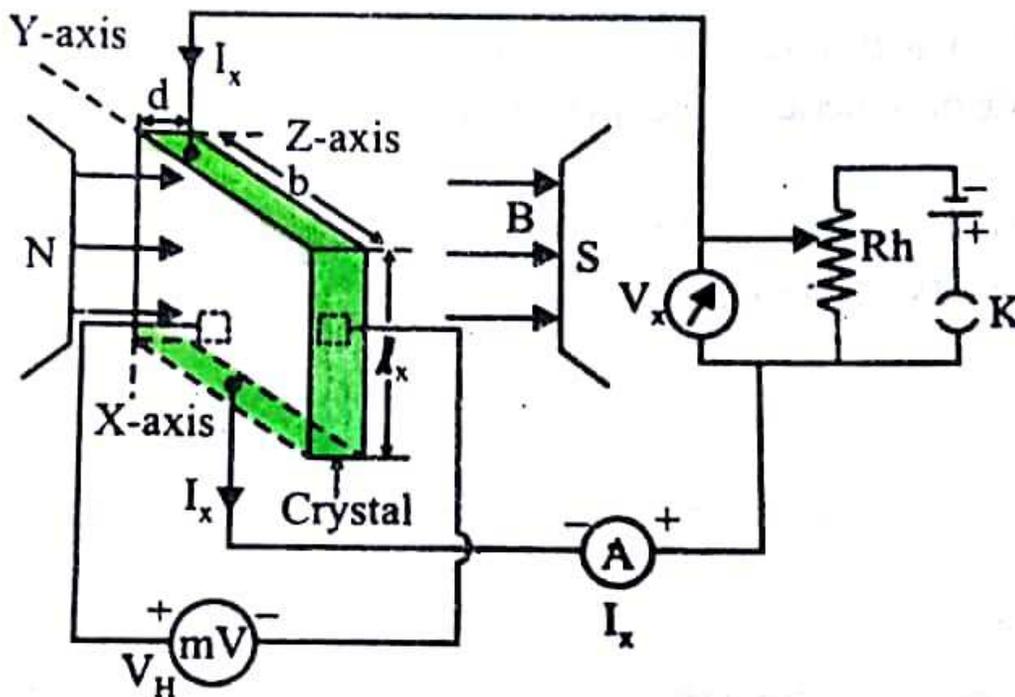


Fig. 14.5: Circuitry of Hall Effect Experimental Arrangement

A conducting semiconductor slab as shown in Fig. 14.5 with length ($l=l_x$) in the x direction, width ($w = b$) in the y direction and thickness ($t=d$) in the z direction. The magnetic field B is also applied along z axis, current I_x is made to flow along x -axis then Hall voltage V_H is developed across the face that are perpendicular to y axis and perpendicular to l_x (is the length of the crystal along x axis). Hall voltage V_H is measured with the help of millivoltmeter and magnetic field B_z measured in gauss or weber/meter² with the help of calibrated flux meter or ballistic Galvanometer.

14.6 PROCEDURE

We have to follow the following steps:

8. Place the specimen in the magnetic field of the strong magnet and make other connection as shown in figure 14.5.
9. Allow some amount of current, I_x (measured by ammeter), with the help of variable resistor or rheostat, R_h to flow through the semiconductor crystal along x-axis.
10. Measure Hall voltage, V_H with the help of millivolt-meter and applied voltage V_x to flow I_x by the help of voltmeter.
11. Change value of I_x in steps by rheostat, R_h , and not corresponding value of V_x and V_H . Take many readings to fill the observation table.
12. Plot a graph in V_H and I_x values. It will be a straight line whose slope will be given by

$$\text{Tan}\theta = \frac{V_H}{I_x}.$$
13. Measure magnetic field (B) with a gauss metre or flux metre and find the actual field in the crystal, $B_z = \mu B$.

14.7 OBSERVATION

Observation table for the measurement of Hall voltage (V_H), applied voltage (V_x), and current (I_x) is given below. We can use the following known values from the specimen,

- Permeability of the specimen, $\mu = \dots\dots\dots$
- Magnetic field, $B = \dots\dots\dots$ gauss or weber/ metre²
- Actual Magnetic field in the crystal, $B_z = \mu B = \dots\dots\dots$ gauss or weber/ metre²
- Width of the Crystal along z- axis, $d = \dots\dots\dots$ meter
- Width of the Crystal along y-axis, $b = \dots\dots\dots$ meter
- Length of the Crystal along x-axis, $l_x = \dots\dots\dots$ meter.

Table 1: Determination of Hall voltage (V_H), applied voltage (V_x), and current (I_x)

S. No	current (I_x) in ampere	applied voltage (V_x) in volt	Hall voltage (V_H) in millivolt
.			

1	....	....	....
2			
3	.....	.....	.....
4	....	....	.....
.
.			

14.8 CALCULATION AND DISCUSSION

A graph is plotted between V_H and I_x , which is shown in figure 14.8.

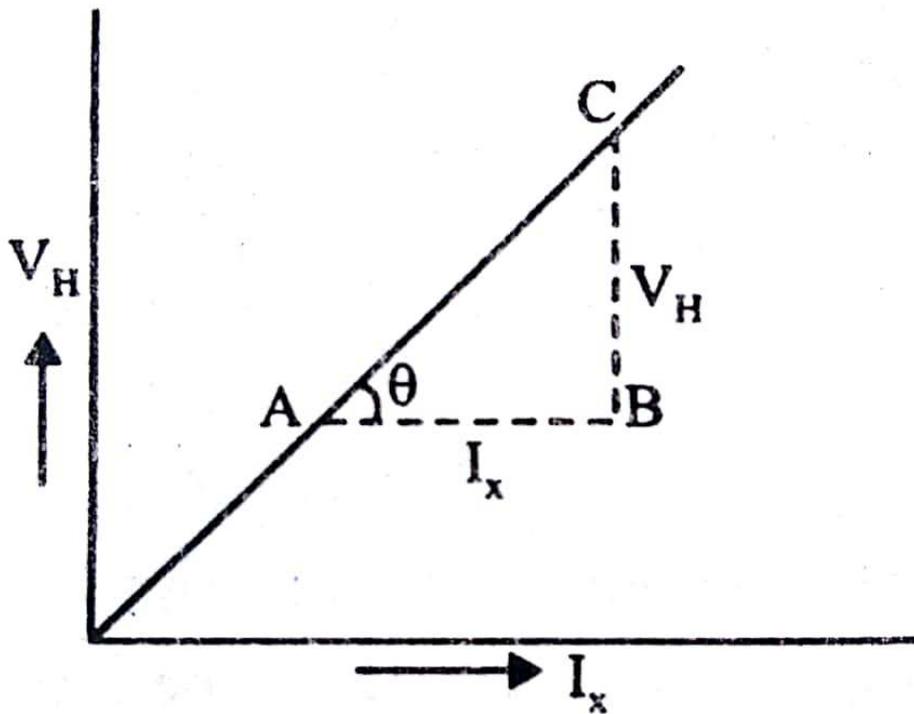


Figure 14.8. Graph between V_H and I_x .

From the graph slope is found

$$\tan\theta = \frac{V_H}{I_x} = \frac{BC}{AB}$$

14.9 RESULTS

Using the value of slope we can get the following results.

(1) Hall coefficient (R_H):

Form equation 14.7,

$R_H = \left(\frac{1}{nq}\right) = - \left(\frac{V_H}{I_x}\right) \cdot \left(\frac{d}{B_z}\right) \cdot 10^4 \text{ meter}^3/\text{coulomb}$. Substituting the value of slope from graph, the value of Hall coefficient, R_H is as

$$R_H = \tan \theta \cdot \left(\frac{d}{B_z}\right) \cdot 10^4 \text{ meter}^3/\text{coulomb}$$

$$R_H = \dots\dots\dots \text{meter}^3/\text{coulomb}$$

(2) Number of charge carriers(n):

Form equation 14.8, number of charge carriers per unit volume in the semiconductor crystal n (electron concentration in n type semiconductor and hole concentration in p type semiconductor) formula is given by

$$n = \left(\frac{1}{R_H q}\right) (\text{meter})^{-3}$$

Substituting the value of R_H from above and $q = 1.6 \times 10^{-19} \text{ C}$, the value of number of charge carriers, is

$$n = \dots\dots\dots (\text{meter})^{-3}$$

(3) Hall angle (Φ):

Form equation 14.9, Hall angle can be found using the formula

$$\Phi = \left(\frac{V_H}{V_x}\right) \cdot \left(\frac{l_x}{w}\right) \text{ rad}$$

Where $w = b$ is the width of crystal along y direction, l_x and width b both are measured in meter. Substituting the value of V_H and V_x from observation table or finding the slope between V_H and V_x , the Hall angle is

$$\Phi = \dots\dots\dots \text{rad}$$

(4) Mobility (m_μ):

Form equation 14.10, to determine mobility we can write the expression

$$m_\mu = \left(\frac{\Phi}{B_z}\right) \text{ rad. meter}^2/\text{weber}$$

Substituting the value of Φ and B_z , the mobility is,

$$m_\mu = \dots\dots\dots \text{rad. meter}^2/\text{weber}$$

14.10 STANDARD RESULTS

The standard values of sample are available in the laboratory.

14.11 PERCENTAGE ERROR

$$\% \text{ Error} = \frac{|\text{observed value} - \text{standard value}|}{\text{standard value}} \times 100 \%$$

14.12 PRECAUTION AND SOURCE OF ERROR

- There should be no disturbance near the experiment setup.
- Reading and graph should be taken carefully.
- Hall voltage developed is very small and should be measured accurately with the help of a millivolt-meter or potentiometer.
- Current Through the crystal should be strictly within the permissible limits.
- Sensitive voltmeter and sensitive ammeter should be used.
- There should not be any fluctuation on the power.

14.13 VIVA-VOCE QUESTION AND ANSWERS

Question 1: What is Hall Effect?

Answer: When an electrical current passes through a sample placed in a magnetic field, a potential difference is developed across the material in a direction perpendicular to both the current and to the magnetic field. This effect is known as the Hall Effect.

Question 2: What is the dependency of Hall potential with current and magnetic field?

Answer: It is proportional to the current and to the magnetic field.

Question 3: What is mobility?

Answer: It is the drift velocity of the charge carrier acquired per unit electric field.

Question 4: On what factors does the sign of Hall potential depend?

Answer: It depends upon the nature of charge carriers. Thus by noting the direction of Hall potential and the magnetic field, the nature of charge carriers may be determined by the use of Fleming's left hand rule.

Question 5: What is the main cause of Hall potential?

Answer: Force experienced by moving charge carriers in perpendicular magnetic field is the main cause of Hall potential.

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EXPERIMENT 15: e/m MILLIKAN'S METHOD

Structure

- 15.1 Objectives
- 15.2 Introduction
- 15.3 Apparatus Used
- 15.4 Theory and Formula Used
- 15.5 About apparatus
- 15.6 Procedure
- 15.7 Observation
- 15.8 Calculation and Discussion
- 15.9 Result
- 15.10 Standard Result
- 15.11 Percentage error
- 15.12 Precaution and source of error
- 15.13 Viva-voce questions and Answers
- 15.14 References

15.1 OBJECTIVES:

After performing this experiment, you should be able to understand

- What is electronic charge?
- What is e/m ratio?
- What is quantization of charge?
- How to measure the fundamental unit of charge more accurately and precisely?
- What is terminal velocity?
- What is Millikan's Oil Drop Method?
- How to determine the value of electronic charge by Millikan's Oil Drop Method?
- Adjustment of the experimental arrangement of Millikan's Oil Drop Method.

15.2 INTRODUCTION:

Millikan's oil-drop experiment is recognized as a major contribution to twentieth century physics. They established the quantization of electric charge, the existence of a fundamental unit of charge, and also measured that unit of charge precisely. As Gullstrand remarked in his Nobel Prize presentation speech, Millikan's aim was to prove that electricity really has the atomic structure, which, on the base of theoretical evidence, it was supposed to have. By a brilliant method of investigation and by extraordinarily exact experimental technique Millikan reached his goal. Even leaving out of consideration the fact that Millikan has proved by these researches that electricity consists of equal units, his exact evaluation of the unit has done physics an inestimable service, as it enables us to calculate with a higher degree of exactitude a large number of the most important physical constants.

15.3 APPARATUS USED:

Millikan apparatus, atomizer, oil, rheostat, voltmeter, power supply, commutator and stop watch.

15.4 THEORY AND FORMULA USED:

The experimental apparatus is shown in Figure (15.1). Millikan allowed a single oil drop to fall a known distance in air. Millikan did not measure the time of fall from rest, but allowed the drop to fall freely for a short distance before it passed a crosshair, which was the start of the time measurement. Because of air resistance the drop was then traveling at a constant, terminal velocity. After the drop passed a second crosshair, which determined the time of fall at constant speed for the known distance between the crosshairs, an electric field was turned on.

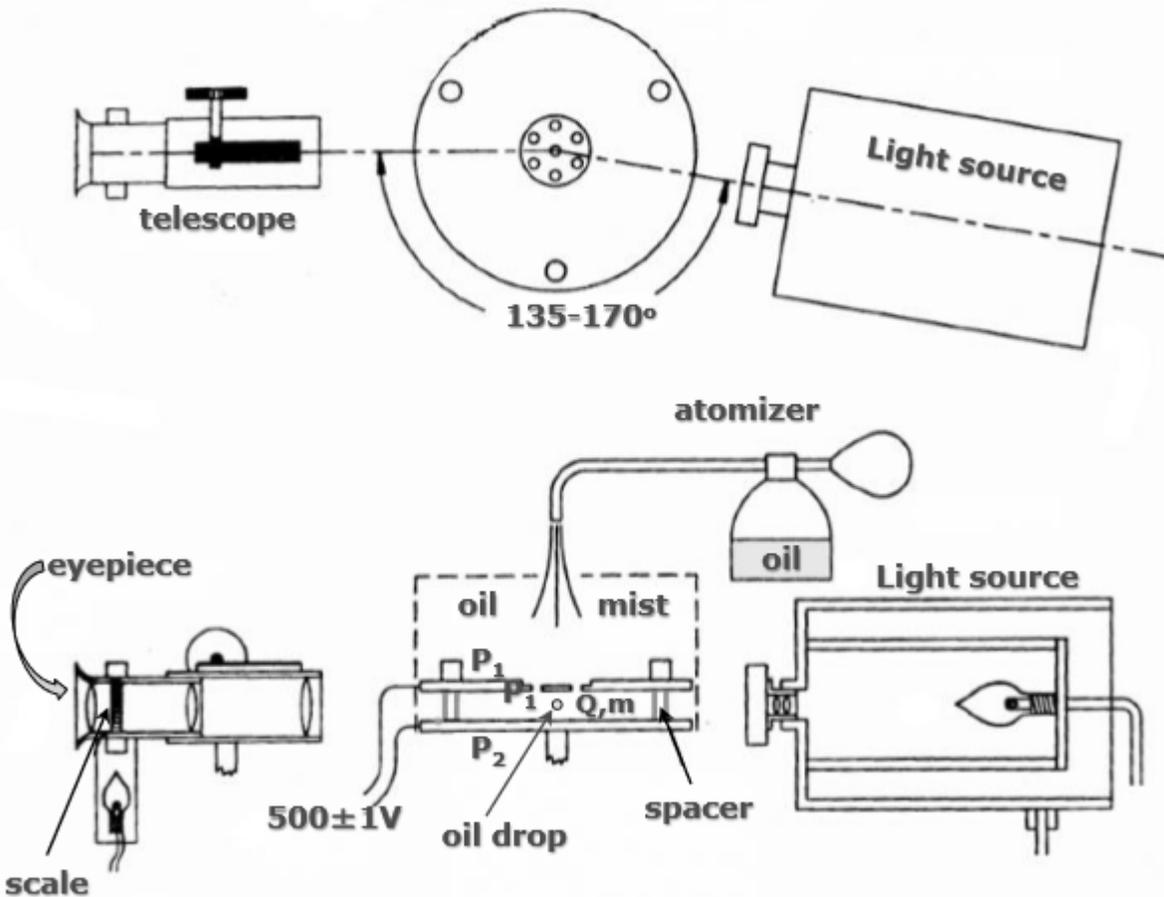


Figure 15.1: Millikan's oil-drop experiment.

The charged oil drops then traveled upward at a different constant speed and the time to ascend the same distance was measured. These two time measurements allowed the determination of both the mass of the drop and its total charge. The equation of motion of an oil drop falling under an upwards electric field E is

$$m\ddot{x} = mg + K\dot{x} - \frac{4}{3}\rho\pi a^3 g - qE \quad \dots\dots (15.1)$$

Where $K\dot{x}$ is force of force of viscosity, q is the drop's charge, m its mass, $\frac{4}{3}\rho\pi a^3 g$ is the buoyant

force of air and qE the force due to electric field. According to Stokes' law, which holds for a continuous retarding medium, $K = 6\pi\eta a$, where a is the drop's radius, ρ density of air, σ density of oil and η the air's viscosity. Because all measurements were made at terminal velocities $\ddot{x} = 0$, whence

$$0 = mg + 6\pi\eta a \dot{x} - \frac{4}{3}\rho\pi a^3 g - qE \quad \dots\dots (15.2)$$

$$0 = \frac{4}{3}\sigma\pi a^3 g + 6\pi\eta a \dot{x} - \frac{4}{3}\rho\pi a^3 g - qE \quad \dots\dots\dots (15.3)$$

$$qE = \frac{4}{3}(\sigma - \rho)\pi a^3 g + 6\pi\eta a \dot{x} \quad \dots\dots\dots (15.4)$$

$qE = m^*g + 6\pi\eta a \dot{x}$, where $m^* = \frac{4}{3}(\sigma - \rho)\pi a^3$ is mass compensated for the buoyant force

of air. If we consider two situation for terminal velocity (i) when no field is applied $E = 0$, then $\dot{x} = v_g$ and (ii) when field is applied then $\dot{x} = v_f$. Therefore, for two different cases, from

equation (15.4) we can get,

$$0 = m^*g + 6\pi\eta a v_g \quad \dots\dots\dots (15.5)$$

$$qE = m^*g + 6\pi\eta a v_f \quad \dots\dots\dots (15.6)$$

From these equations, $v_g = \frac{-m^*g}{6\pi\eta a}$, $v_f = \frac{qE - m^*g}{6\pi\eta a}$ and $v_f = \frac{qE}{6\pi\eta a} + v_g$. We can also

find out the radius of oil drop in terms of terminal velocity using equation (15.5).

$$\left| \frac{4}{3}(\sigma - \rho)\pi a^3 g \right| = \left| 6\pi\eta a v_g \right|$$

$$a^2 = \frac{9}{2} \frac{\eta v_g}{(\sigma - \rho)g}$$

$$a = \left[\frac{9}{2} \frac{\eta v_g}{(\sigma - \rho)g} \right]^{\frac{1}{2}} \dots\dots\dots (15.7)$$

Subtracting equation (15.5) from (15.6) we can write,

$$qE = 6\pi\eta a v_f - 6\pi\eta a v_g$$

$qE = 6\pi\eta a (v_f - v_g)$ or $qE = \frac{m^*g}{v_g} (v_f - v_g)$ or $q = \frac{m^*g}{E} \frac{(v_g - v_f)}{(v_g)}$. Thus charge of oil

drop can be expressed as

$$q = \frac{m^*g}{E} \left(1 - \frac{v_f}{v_g} \right) \quad \dots\dots\dots (15.8)$$

Substituting the values of m^* , equation (15.8) becomes

$$q = \frac{4(\sigma - \rho)\pi a^3 g}{3E} \left(1 - \frac{v_f}{v_g} \right) \quad \dots\dots\dots (15.9)$$

Since the size of oil drop is very small, therefore radius a can be replaced using equation (15.7). Thus,

$$q = \frac{4(\sigma - \rho)\pi g}{3E} \left[\frac{9\eta v_g}{2(\sigma - \rho)g} \right]^{\frac{3}{2}} \left(1 - \frac{v_f}{v_g} \right)$$

$$q = 9 \frac{\pi(\eta v_g)^{\frac{3}{2}}}{E} \left[\frac{2}{(\sigma - \rho)g} \right]^{\frac{1}{2}} \left(1 - \frac{v_f}{v_g} \right) \quad \dots\dots\dots (15.10)$$

The ratios of distance d to times of fall and rise, t_g and t_f can be substituted for the velocities, substitute $v_g = \frac{d}{t_g}$ and $v_f = \frac{d}{t_f}$ in equation (15.10), we get $q = 9 \frac{\pi(\eta \frac{d}{t_g})^{\frac{3}{2}}}{E} \left[\frac{2}{(\sigma - \rho)g} \right]^{\frac{1}{2}} \left(1 - \frac{t_g}{t_f} \right)$.

Where d is the known distance between the crosshairs to fall and rise in the absence and presence of field. where q , the total charge on the drop, is assumed to be an integral multiple of a unit e , d is the distance traveled, either up or down, and g is the acceleration of gravity. If the charge $q = ne$ then,

$$q = ne = 9 \frac{\pi(\eta \frac{d}{t_g})^{\frac{3}{2}}}{E} \left[\frac{2}{(\sigma - \rho)g} \right]^{\frac{1}{2}} \left(1 - \frac{t_g}{t_f} \right) \quad \dots\dots\dots (15.10)$$

During fall and rise in the absence and presence of field, direction of velocity changes, v_f should be negative (direction of viscous force changes). Therefore, equation (15.10) may be expressed as

$$q = ne = 9 \frac{\pi(\eta \frac{d}{t_g})^{\frac{3}{2}}}{E} \left[\frac{2}{(\sigma - \rho)g} \right]^{\frac{1}{2}} \left(1 + \frac{v_f}{v_g} \right) \quad \dots\dots\dots (15.11)$$

The electric field in terms of potential difference is $E = \frac{V}{d}$, thus

$$q = ne = 9 \frac{\pi d(\eta \frac{d}{t_g})^{\frac{3}{2}}}{V} \left[\frac{2}{(\sigma - \rho)g} \right]^{\frac{1}{2}} \left(1 + \frac{v_f}{v_g} \right) \quad \dots\dots\dots (15.12)$$

This equation will help us to determine the charge of oil drop, which should be perfect multiple of charge of electron ($e = 1.6 \times 10^{-19}$ C).

15.5 ABOUT APPARATUS

The description of Millikan's apparatus for the measurement of electronic charge is shown in figure 15.5. The apparatus consists of an earthed metal chamber C having two windows. Inside the chamber there are two plane parallel circular plates A and B separated from each other by glass plates. The upper plate A has 4 or 5 tiny holes to sprinkle charged oil drops in the region between the plates.

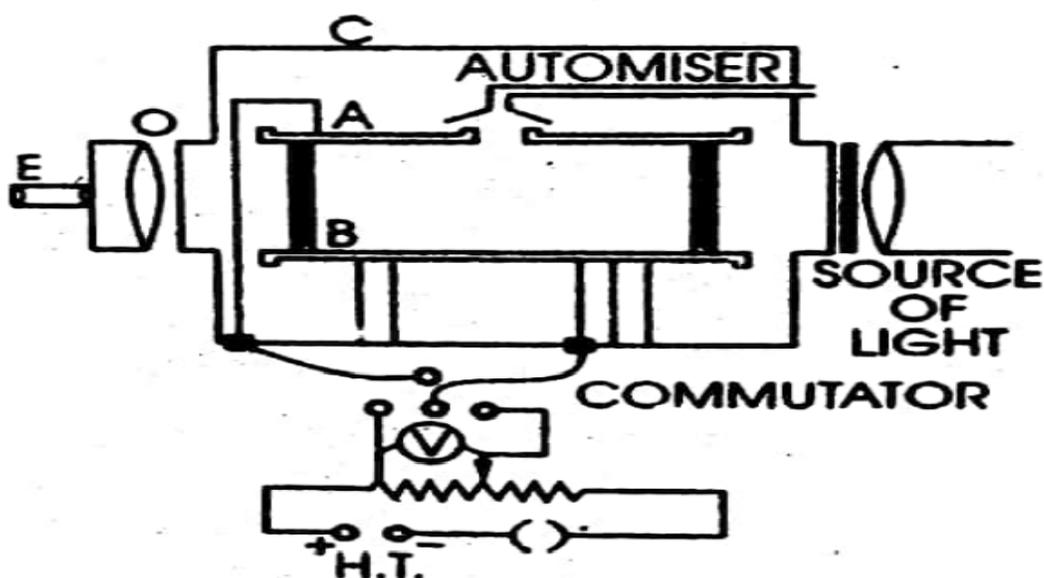


Figure 15.5: Millikan's oil-drop experimental apparatus.

The region is illuminated by a source of light and the moving drops appear as shining stars which are viewed with the help of a long focus microscope. The eyepiece of the microscope provided with two cross wires is at a known distance apart. A potential difference is maintained between the two plates with the help of H.T. The vertical velocity of the drop can be determined by observing the time taken by the drop to move between the measured distances. The speed of the charged drop is measured (i) under gravity alone and (ii) under a known electric field E . Here, it should be well understood that the drops are charged by friction during the process of spraying by an atomizer.

15.6 PROCEDURE

We have to follow the following steps:

1. The adjustments are made as shown in figure (15.5) i.e. the plates A and B are connected of H.T. through a commutator and potential divider.
2. The voltmeter is used to be measure this applied voltage.
3. The lamp illuminates the field of view which is focused with the help of large focusing microscope.
4. The electric field is set on and oil is sprayed by atomizer.
5. The charge drops appear to be moving.
6. Any one of the drops can be kept in the field of view by reversing the commutator.
7. Theselected charged drops are allowed to fall under gravity only (when field is switched off) and its velocity v_1 is found.
8. When these drops approaches to plate B, electric field is switched on so that drops can moves upwards.
9. The drop is now allowed to move under the field (when field is switched on) and its velocity v_2 is measured.
10. Velocities of drops can be measure using distance divided by time travelled by the drops between two positions of cross wire.
11. The voltmeter reading is also noted.

15.7 OBSERVATION

Observation table for the measurement of velocities v_1 and v_2 is given below. We can use the following known values from the specimen,

- Temperature =°C.
- Pressure = atmospheric.
- Viscosity of air η =poise.
- Density of oil σ =gm/c.c.
- Density of air ρ =gm/c.c.
- Distance between the plates d =cm
- Magnification produces by eyepiece =

Table 1: Determination of velocity (v_1) and velocity (v_2).

S.	Potential ↓	Motion of drops under gravity only (electric field is switched off)	Motion of drops under (electric field is switched on)

No.		Distance travelled in the scale	Actual distance	Time taken	velocity (v ₁)	Distance travelled in the scale	Actual distance	Time taken	velocity (v ₁)
1
2
3
4
.	
.								

15.8 CALCULATION AND DISCUSSION

Equation (15.12) will help us to determine the charge of oil drop, which should be perfect multiple of charge of electron (e = 1.6 x 10⁻¹⁹ C). Substituting the values of velocities determined in table-1 and other parameters in S.I. system, we can calculate the charge

$$q = ne = 9 \frac{\pi d (\eta v_g)^{\frac{3}{2}}}{V} \left[\frac{2}{(\sigma - \rho)g} \right]^{\frac{1}{2}} \left(1 + \frac{v_f}{v_g} \right)$$

$$= \dots\dots\dots C$$

15.9 RESULTS

The charge on oil drops =C or e.s.u.

15.10 STANDARD RESULTS

The standard value of charge should be a perfect multiple of the charge of an electron ($e = 1.6 \times 10^{-19}$ C).

15.11 PERCENTAGE ERROR

$$\% \text{ Error} = \frac{|\text{observed value} - \text{standard value}|}{\text{standard value}} \times 100 \%$$

15.12 PRECAUTION AND SOURCE OF ERROR

- There should be no disturbance near the experiment setup.
- Plates should be clean and parallel to each other.
- The values of η , σ and ρ should be taken at the experimental temperature.
- Commutator should be used properly.
- There should not be fluctuation in the voltage.
- Non volatile oil should be used.
- Buoyancy correction should be applied to reduce the deviation in the result.
- Mean free path correction should be applied.
- Reading should be taken carefully.
- Sensitive voltmeter and sensitive ammeter should be used.
- There should not be any fluctuation on the power.

15.13 VIVA-VOCE QUESTION AND ANSWERS

Question 1: How much is the charge on an electron?

Answer: It is 1.6×10^{-19} C or 4.8025×10^{-10} e.s.u..

Question 2: What is the relation between coulomb and e.s.u.?

Answer: It is $1 \text{ C} = 3 \times 10^9 \text{ e.s.u.}$

Question 3: How do the oil drops become charged?

Answer: They are charged by friction when they pass through the nozzle of the atomizer.

Question 4: Can you tell about the nature of charge on a particular drop?

Answer: Yes, If applying positive voltage to the upper plate the drop moves up then it is negatively charged.

Question 5: When does the drop acquire a steady velocity?

Answer: In the absence of an electric field, the drop acquires steady velocity when the viscous force due to air becomes equal to the force of gravity. In the second case when the field is switched on,

it acquires steady velocity when the net upward force due to electric field becomes equal to the viscous force and force of gravity.

Question 6: What is the formula for viscous force?

Answer: It is $6\pi\eta a\dot{x}$, where η is the coefficient of viscosity, \dot{x} is the velocity and a is the radius of drops.

Question 7: What is the equation of motion for oil drop in air?

Answer: The equation of motion of an oil drop falling under an upwards electric field E is $m\ddot{x} = mg + K\dot{x} - \frac{4}{3}\rho\pi a^3g - qE$. Where $K\dot{x}$ is force of force of viscosity, q is the drop's charge, m its mass, $\frac{4}{3}\rho\pi a^3g$ is the buoyant force of air and qE , the force due to electric field.

Question 8: What is the concept you arrive at after finding the net charge on the oil drops?

Answer: That the net charge is quantized.

Question 9: What is the concept of quantized charge?

Answer: The charge of oil drop should be perfect multiple of charge of electron ($e = 1.6 \times 10^{-19}$ C).

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EXPERIMENT 16: RESISTIVITY OF SEMICONDUCTOR USING FOUR PROBE METHOD

Structure

- 16.1 Objectives
- 16.2 Introduction
- 16.3 Apparatus Used
- 16.4 Theory and Formula Used
- 16.5 About apparatus
- 16.6 Procedure
- 16.7 Observation
- 16.8 Calculation and Discussion
- 16.9 Result
- 16.10 Standard Result
- 16.11 Percentage error
- 16.12 Precaution and source of error
- 16.13 Viva-voce questions and Answers
- 16.14 References

16.1 OBJECTIVES:

After performing this experiment, you should be able to understand

- What is resistivity?
- What is resistivity of semiconductor?
- What is Ohm's Law?
- What is two probe method?
- What are drawbacks of two probe method?
- What is four probe method?
- What is energy band gap of a semiconductor?
- What is Temperature dependence of resistivity of a semiconductor?
- How to determine the resistivity of semiconductor using Four Probe Method?
- How to determine the energy band gap of a semiconductor using four probe method?
- Adjustment of the experimental arrangement of Four Probe Method.

16.2 INTRODUCTION:

Four Probe Method is one of the standard & most commonly used method for the accurate measurement of resistivity. It overcomes the problem of contact resistance and also offers several other advantages. Accurate resistivity measurement in samples having a variety of shapes is possible by this method. The pressure contacts provided in the Four Point Arrangement are especially useful for quick measurement. This setup can measure samples of reasonably wide resistivity range (micro ohm to mega ohm).

16.3 APPARATUS USED:

Four Probes arrangement (it should have four probes, coated with zinc at the tips. The probes should be equally spaced and must be in good electrical contact with the sample), Sample (Germanium or silicon crystal chip with non-conducting base), Oven (for the variation of temperature of the crystal from room temperature to about 200 °C), A constant current generator (open circuit voltage about 20 volt, current range 0 to 10 mA), Millivolt meter (mV range from 100 mV to 3V, electronic), power supply for oven and a thermometer.

16.4 THEORY AND FORMULA USED:

For detailed explanation of principles and theory involved in this experiment, we have to understand some basic terms of current electricity which are ohm's law, resistivity, two probe method and its drawbacks. Then we will discuss theory and formula used in this experiment.

(a) Ohm's law: If physical conditions (like temperature, mechanical stress) remain unchanged,

then potential difference across two ends of a conductor is proportional to current flowing through a conductor. The constant of proportionality, R , is called resistance of the conductor.

(b) Resistivity: At a constant temperature, the resistance, R , of a conductor is (i) proportional to its length and (ii) inversely proportional to its area of cross-section, the constant of proportionality, ρ , is called resistivity of material of the conductor. Resistivity of a material is equal to the resistance offered by a wire of this material of unit length and unit cross-sectional area. Unit of resistance is ohm (Ω), and unit of resistivity is ohm-meter ($\Omega\text{-m}$). The Ohm's law can also be expressed as $\mathbf{E} = \rho\mathbf{J}$ where \mathbf{J} is the current density and \mathbf{E} is the electric field set up in the resistance. The scalar equation $E = \rho J$ is only valid for resistors and conductors which are homogeneous and isotropic, that is the conductivity (reciprocal of resistivity) is uniform throughout the conductor, carrying a uniform electric current per unit cross-sectional area, J , through a uniform internal electric field E , all in one dimension only.

(c) Two probe method: For a long thin wire-like geometry of uniform cross section or for a long parallelepiped shaped sample of uniform cross section, the resistivity ρ can be measured by measuring voltage drop across the sample due to passage of known (constant) current through the sample, as shown in Fig.16.4.1. XY is the specimen whose resistivity is to be measured. The battery E supplies current (in through probe 1 and out through probe 2). Let the current in the specimen is I (ampere). It is measured by the ammeter A . The potential difference between the two contacts (probe 1 and probe 2) at the ends of the specimen is V (volt). It is measured by the voltmeter V . Let l is length of the specimen between the two

probes and A its area of cross-section, then, the resistivity of the specimen is

$$\rho = \frac{VA}{Il}$$

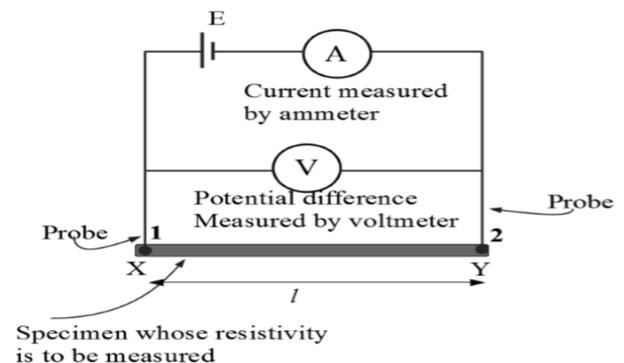


Figure 16.4.1 Two probe method of measuring resistivity of a sample.

(d) Drawbacks of two probe method:

- (i) The major problem in such method is error due to contact resistance of measuring leads.
- (ii) The above method cannot be used for materials having random shapes. For some type of materials soldering the test leads would be difficult.
- (iii) In case of semiconductors, the heating of samples due to soldering results in injection of impurities into the materials thereby affecting the intrinsic electrical resistivity. Moreover, certain metallic contacts form Schottky barrier on semiconductors.

To overcome first two problems, a collinear equidistant four-probe method is used. This method provides the measurement of the resistivity of the specimen having wide variety of shapes but

with uniform cross-section. The soldering contacts are replaced by pressure contacts to eliminate the last two problems discussed above.

(e) Four probe method:

The Four Probe arrangement is shown in Figure (16.1). It has four individually spring loaded probes. The probes are collinear and equally spaced. The probes are mounted in a teflon bush, which ensure a good electrical insulation between the probes. A teflon spacer near the tips is also provided to keep the probes at equal distance. The probe arrangement is mounted in a suitable stand, which also holds the sample plate and RTD sensor. This stand also serves as the lid of PID Controlled Oven. Proper leads are provided for current, Voltage & Temp. measurement with their universal connectors. For current measurement there is three pin connector which can be connected to the CCS-01/ LCS-02 as per requirement of sample. For voltage measurement BNC connector is used connected to DMV-001 unit. For temperature measurement, a two pin connector is provided for connection with PID- Controlled oven unit PID-200 at connector marked as Temperature Sensor.

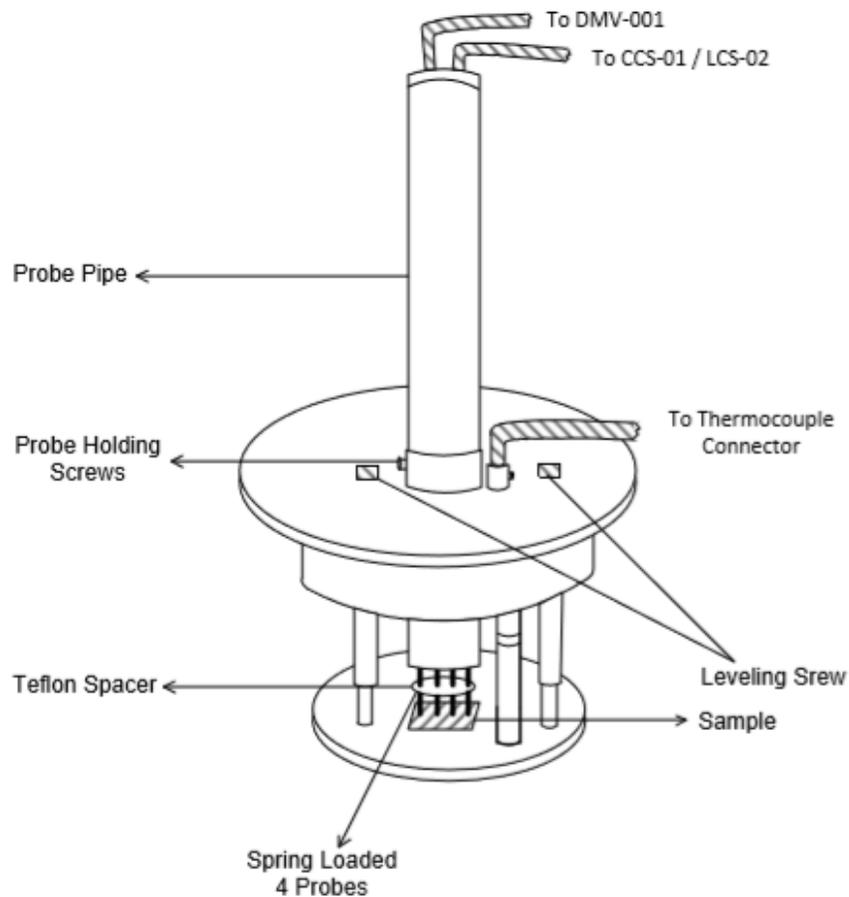


Figure 16.1: Four Probe Arrangement.

Three levelling screws are provided in Four Probe arrangement by which we can adjust the level of platform to make it horizontal. A probe holding screw is provided at the collar of the arrangement. Initially it should be in loose position, to allow free movement of Probe Pipe. After placing the sample, the Probe Pipe should be lowered so that all four pins touch the sample. Further Press the pipe very lightly so that the assured firm contact is made of all Four Pins with the sample. Tighten the Probe Holding Screw at this position. The Probe Arrangement is ready with the sample for the experiment. Four sharp probes are placed on a flat surface of the material to be measured (Fig.16.2).

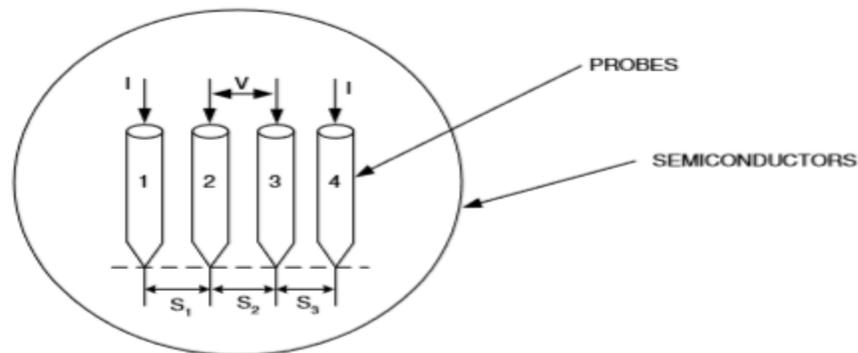


Figure 16.2: Model for the four probe resistivity measurement

The current is passed through the two outer electrodes, and the floating potential is measured across the inner pair. If the flat surface on which the probes rest is adequately large, it may be considered to be a semi-infinite volume. To prevent minority carrier injection and make good contacts, the surface on which the probes rest, maybe mechanically lapped. The circuit used for measurement is illustrated schematically in Fig. 16.3.

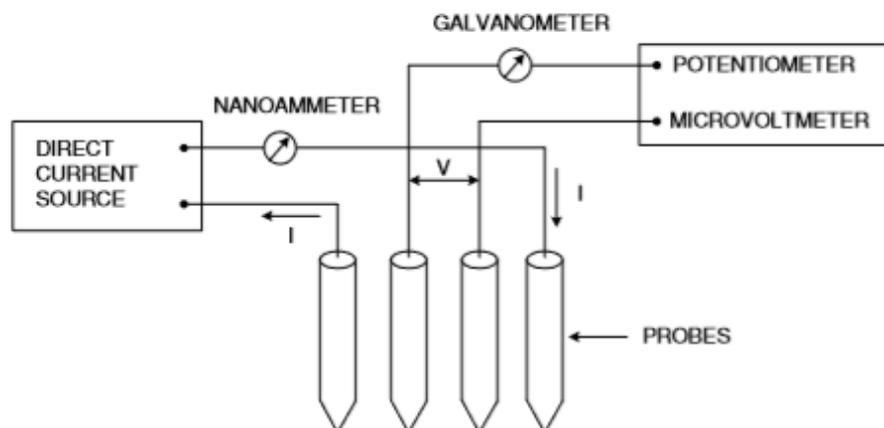


Figure 16.3: Circuit used for resistivity measurement

A nominal value of probe spacing, which has been found satisfactory, is about an equal distance of 1.0 to 2.0 mm between adjacent probes. In order to use the four-probe method, it is assumed that:

1. The resistivity of the material is uniform in the area of measurement.
2. If there is minority carrier injection into the semiconductor by the current - carrying electrodes, most of the carriers recombine near the electrodes so that their effect on the conductivity is negligible. (This means that the measurements should be made on surface, which has a high recombination rate, such as mechanical by lapped surfaces).
3. The surface on which the probes rest is flat with no surface leakage.
4. The four probes used for resistivity measurements are equally spaced and collinear.
5. The diameter of the contact between the metallic probes and the semiconductor should be small compared to the distance between probes.
6. The surfaces of the material may be either conducting or non-conducting.
7. A conducting boundary (such as copper) is one on which the sample is plated or placed. A non-conducting boundary is produced when the surface of the sample is in contact with an insulator.

(f) Resistivity Measurements on a Large Sample of Germanium (semiconductor).

We assume that the metal tip is infinitesimal and sample is semi-infinite in lateral dimensions. For bulk samples where the sample thickness, $w \gg s$, the probe spacing, we assume a spherical protrusion of current emanating from the outer probe tips. The resistivity is

$$\rho_0 = \frac{V}{I} \cdot (2 \pi s) = \dots\dots\dots \text{ohm-Cm. Where,}$$

V = floating potential difference between the inner probes, unit: volt

I = current through the outer pair of probes, unit: ampere

s = spacing between point probes, unit: meter

ρ_0 = resistivity, unit: ohm meter

(g) Resistivity Measurements on a Thin Slice Sample of Germanium (semiconductor).

Fig.16.1 shows the resistivity probes on a die of material. If the side boundaries are adequately far from the probes the die may be considered to be identical to a slice. For this case of a slice of thickness w and with a non-conducting bottom surface the resistivity is computed by means of the divisor $f(w/s)$. Firstly, we try to find the resistivity ρ corresponding to a temperature in K using the relation

$$\rho = \frac{\rho_0}{f\left(\frac{w}{s}\right)} \quad \text{where, } \rho_0 = \frac{V}{I} \cdot (2 \pi s) = \dots\dots\dots \text{ohm-Cm.}$$

Corresponding to different values of (V) voltage, there will be different values of ρ_0 . Now we can calculate the value of w/s of semiconductor sample then corresponding to this value, choose the value of the function $f(w/s)$ from the following table 2.

Table 2: value of function $f(w/s)$ of semiconductor sample corresponding to the values of (w/s)

w/s	$f(w/s)$
0.100	13.863
0.141	9.704
0.200	6.931
0.333	4.159
0.500	2.780
1.000	1.504
1.414	1.223
2.000	1.094
3.333	1.0228
5.000	1.0070
10.000	1.00045

If any (w/s) value is not found in the table, then plot a graph in these (w/s) and $f(w/s)$ values. From graph the desired values of $f(w/s)$ corresponding any value of (w/s) can be find out. After choosing $f(w/s)$, calculate the value of resistivity (ρ) for various value of (ρ_0) , i.e. for various values of V which correspond to various values of temperature and tabulate as follows. For smaller values of w/s the function $f(w/s)$ approaches the case for an infinitely thin slice, that is,

$$f(w/s) = \frac{2s \ln 2}{w} \text{ and, } \rho = \frac{\pi W}{\ln 2} \left(\frac{V}{I}\right) = 4.5324 (w) \left(\frac{V}{I}\right). \text{ ----(16.1)}$$

From equation (16.1), we can find out the value of resistivity of semiconductor.

(h) Temperature dependence of resistivity of a semiconductor: Intrinsic semi-conduction

The process in which thermally or optically excited electrons contribute to the conduction is called intrinsic semi-conduction. In the absence of photonic excitation, intrinsic semi-conduction takes place at temperatures above 0 K as sufficient thermal agitation is required to transfer electrons from the valence band to the conduction band. Conductivity for intrinsic semi-conduction, the total electrical conductivity is the sum of the conductivities of the valence and conduction band carriers, which are holes and electrons, respectively. It can be expressed as

$$\sigma = e(n_e \mu_e + n_h \mu_h) \text{ ----(16.2)}$$

where n_e , μ_e are the electron's concentration and mobility, and n_h , μ_h are the hole's concentration and mobility, respectively. The mobility is a quantity that directly relates the drift velocity v_d of charge carriers to the applied electric field E across the material, i.e.,

$\mu = v_d / E$. In the intrinsic region the number of electrons is equal to the number of holes, $n_e = n_h = n_i$, so Equation (16.2) implies that,

$$\sigma = n_i e (\mu_e + \mu_h) \text{ ----(16.3)}$$

(I) Temperature dependence of conductivity:

The electron density (electrons/volume) in the conduction band is obtained by integrating (density of states \times probability of occupancy of states) from the bottom to top of the conduction band. The detailed calculations reveal that,

$$n_i = N T^{\frac{3}{2}} \exp\left(-\frac{E_g}{2kT}\right). \text{ (16.4)}$$

Where N is some constant. Substituting the value of equation (16.4) in equation (16.3) we get,

$$\sigma = e(\mu_e + \mu_h) N T^{\frac{3}{2}} \exp\left(-\frac{E_g}{2kT}\right). \text{ (16.5)}$$

Eq.(16.5) shows that the electrical conductivity of intrinsic semiconductors depends on temperature and decreases exponentially with decreasing temperature.

(J) Temperature dependence of Resistivity:

The resistivity is reciprocal of conductivity. For intrinsic semiconductor, it is (from Eq. (16.5))

$$\rho = \frac{1}{\sigma} = \frac{1}{e(\mu_e + \mu_h) N T^{\frac{3}{2}}} \exp\left(\frac{E_g}{2kT}\right). \quad (16.6)$$

Since the mobility dependence on temperature for semiconductor is such that it is,

$$e(\mu_e + \mu_h) N T^{\frac{3}{2}} \approx \text{constant} \dots \quad (16.7)$$

Therefore, Eq. (16.6) can be written as

$$\rho = A \exp\left(\frac{E_g}{2kT}\right). \quad \dots \quad (16.8)$$

Where A is some constant, taking logarithmic both side we get,

$$\log_e \rho = \log_e A + \left(\frac{E_g}{2kT}\right). \quad (16.9)$$

Equation (16.9) can be written as,

$$\log_{10} \rho = C + \frac{1}{2.303} \left(\frac{E_g}{2kT}\right). \quad (16.10)$$

Where C is a constant. For convenience equation (16.10) can be expressed as,

$$\log_{10} \rho = C + \frac{1}{2.303 \times 10^3} \left(\frac{E_g}{2k}\right) \left(\frac{10^3}{T}\right). \quad (16.11)$$

Thus a graph between log of resistivity, $\log_{10} \rho$, and reciprocal of the temperature, $\left(\frac{10^3}{T}\right)$, should be a straightline as shown in fig.(16.4) and the slope of this graph will give us value of energy band gap of semiconductor. It is

$$\text{Slope} = \frac{\Delta C}{\Delta \left(\frac{10^3}{T}\right)} = \frac{1}{2.303 \times 10^3} \left(\frac{E_g}{2k}\right).$$

Therefore, the value of energy band gap is

$$E_g = (2.303 \times 10^3) \cdot 2k \cdot (\text{Slope}) = \dots \dots \dots eV.$$

Where the value of $k = 8.617 \times 10^{-5} \text{ eV K}^{-1}$.

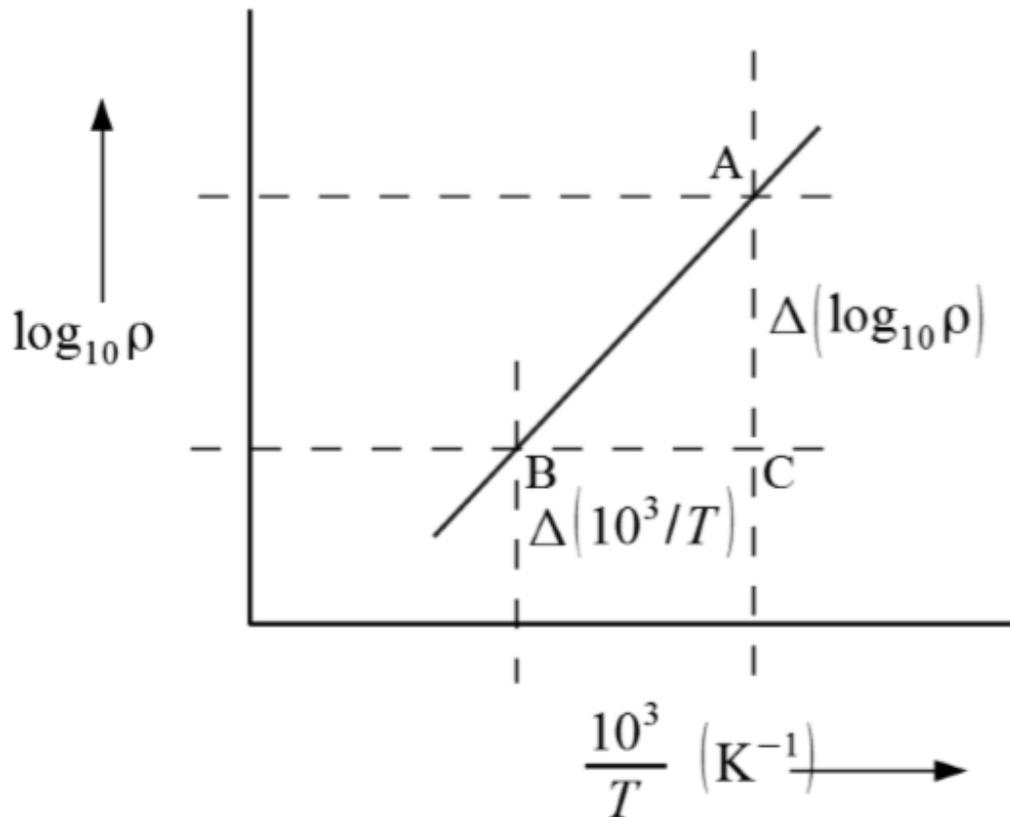


Figure 16.4: Graph between log of resistivity, $\log_{10}\rho$, and reciprocal of the temperature, $\left(\frac{10^3}{T}\right)$.

16.5 ABOUT APPARATUS:

The experimental set up (Fig.16.5) consists of (i) probe arrangement, (ii) sample, (iii) oven, thermometer (0 – 200 C), (iv) constant current generator, (v) oven power supply, (vi) digital panel meter (for measuring voltage & current). The four-probe assembly consists of four spring loaded probes arranged in a line with equal spacing between adjacent probes. These probes rest on a metal plate on which thin slices of samples (whose resistivity is to be determined) can be mounted by insulating their bottom surface using a mica sheet. Different colored leads are provided for carrying current and for voltage measurements. The sample, usually, is brittle, hence do not attempt to mount the sample yourself. This assembly is mounted inside of an oven, so that the four probes and

the sample can be kept inside the oven and sample can be heated up to a temperature of 200°C . The temperature inside the oven can be measured by inserting a thermometer through a hole in the lid. The sample is, normally, germanium crystal in the form of a chip. It is brittle and costly. Therefore, the setup should be handled only after fully understanding the management of probe settings. Contacts of the probes with the crystal should be done very carefully using gentle up/down motion of the screw provided for the purpose. There exists provision for varying the temperature of the oven (up to a maximum of 200°C). Suitable voltage for the oven is obtained through a step-down transformer with a provision for low & high rates of heating.

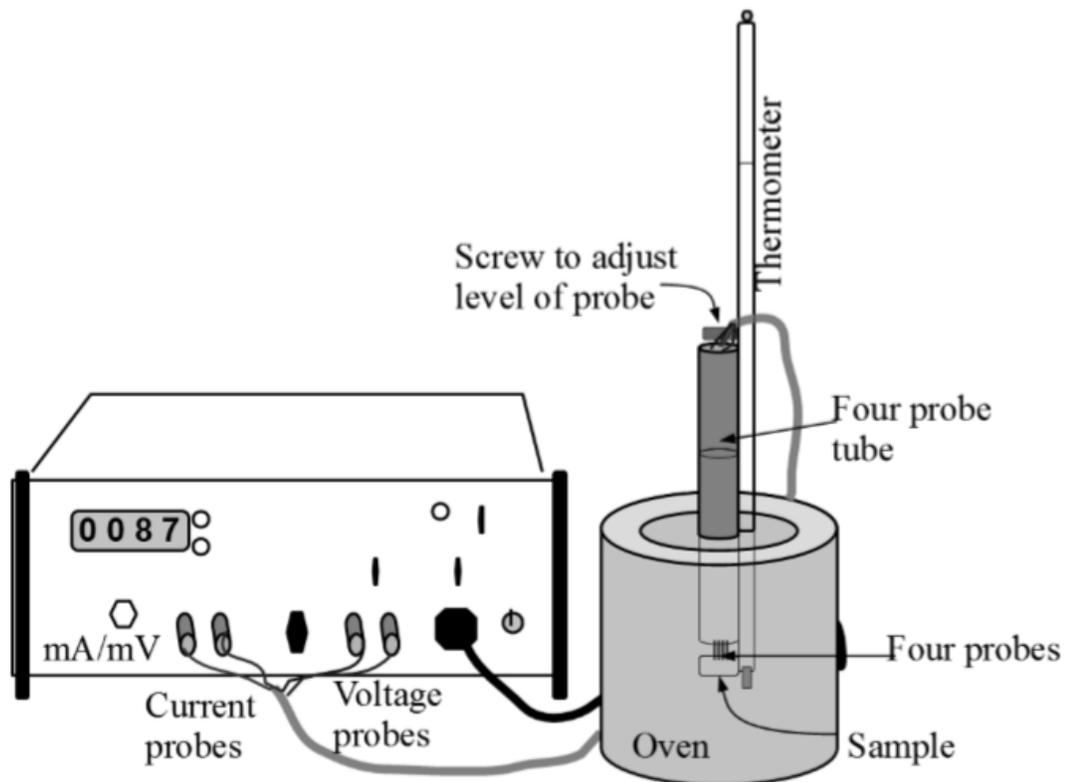


Figure 16.5 : Schematic diagram of four probes method

16.6 PROCEDURE

Refer to figure (16.1) and figure (16.3), we have to follow the following steps:

12. The adjustments are made as shown in figure (16.5)
13. The voltmeter is used to be measure this applied voltage.
14. Connect one pair of probes to direct current source through milli-ammeter and the other pair to milli-voltmeter.

15. Place four Probes arrangement in the oven.
16. Fix the thermometer of oven first then switch on the constant current source and adjust current I to a desired value about to milli-ampere.
17. Connect the oven power supply and start heating. Note the temperature.
18. Measure the inner probe voltage for various temperatures.
19. The milli-ampere reading is also noted. (Should be under desire value.)

16.7 OBSERVATION

Observation table for the measurement of voltage (V) at different values of temperature (T) is given below. We can use the following known values from the specimen,

- Distance between probes (s) =mm
- Thickness of the crystal chip (w) =mm
- Temperature T and voltage V for current (I) =mA (constant).

Table 1: observation of voltage (V) at different values of temperature (T).

S. No.	Temperature (T)		Voltage (V) in mV	Current (I) in mA
	In $^{\circ}C$	In K		
1	20	293	.....	.....
2	25	298	...	...
3	...	.....	.....	.....
4	.....	.....	.....	.....
.

	200	473		
--	-----	-----	--	--

16.8 CALCULATION AND DISCUSSION

Firstly we try to find the resistivity ρ corresponding to a temperature in K using the relation

$$\rho = \frac{\rho_0}{f\left(\frac{w}{s}\right)} \quad \text{where} \quad \rho_0 = \frac{V}{I} \cdot (2 \pi s) = \dots\dots\dots \text{ohm. Cm.}$$

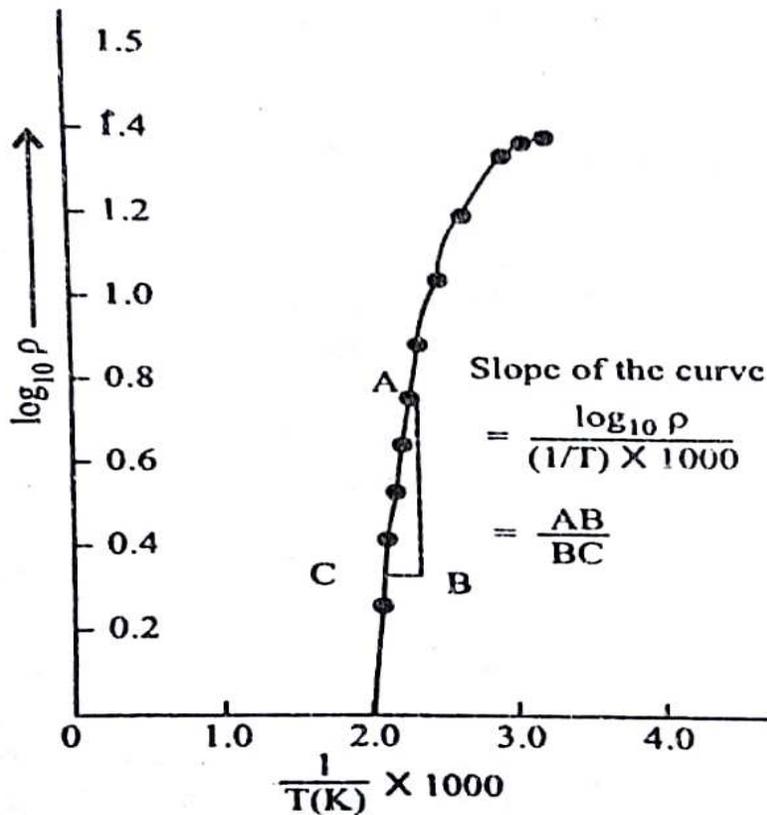
Corresponding to different values of (V) voltage and current (I), there will be different values of ρ_0 . Now we can calculate the value of w/s of semiconductor sample then corresponding to this value, choose the value of the function $f(w/s)$ from the table 2. (refer to subsection (g) of section 16.4.)

If any (w/s) value is not found in the table then plot a graph in these (w/s) and $f(w/s)$ values. From graph the desired values of $f(w/s)$ corresponding any value of (w/s) can be find out. After choosing $f(w/s)$, calculate the value of resistivity (ρ) for various value of (ρ_0), i.e. for various values of V which correspond to various values of temperature and tabulate as follows.

S. No	Temperature (T) <i>In K</i>	Resistivity (ρ) $\Omega\text{-cm}$	$\frac{1}{r} \times 10^3$	$\log_{10}\rho$
1	291	.....	.....	.....
2	293	...	...	...
3	298	.....	.....	.....
4	.....	.....	.....	.....

 473
--	--------------	-----	-----	-----

Finally plot a graph in between $(\frac{1}{T} \times 10^3)$ and $(\log_{10} \rho)$ as shown in figure 16.7.



$$E_g = 2 k \cdot \frac{2.303 \times \log_{10} \rho}{\frac{1}{T}}$$

$$E_g = 0.396 \left(\frac{AB}{BC} \right) \text{ eV.}$$

This graph shows how resistivity of semiconductor varies with the temperature. Find the slope of the curve, which is,

$$\frac{AB}{BC} = \frac{\log_{10} \rho}{\frac{1}{T} \times 1000}$$

The energy band gap of semiconductor germanium is given by

$$E_g = 2 k \cdot \frac{2.303 \times \log_{10} \rho}{\frac{1}{T}}$$

Figure 16.7: Resistivity of semiconductor varies with the temperature

16.9 RESULTS

Two important results are,

(i) Resistivity of semiconductor varies with the temperature, graph between \log of resistivity, $\log_{10} \rho$, and reciprocal of the temperature, $\left(\frac{10^3}{T}\right)$ is plotted for various values.

(ii) The energy band gap of semiconductor (Germanium) is calculated by

$$\text{Slope} = \frac{\Delta C}{\Delta C} = \frac{1}{2.303 \times 10^3} \left(\frac{E_g}{2k} \right)$$

Therefore, the value of energy band gap is

$$E_g = (2.303 \times 10^3) \cdot 2k \cdot (\text{Slope}) = \dots \text{eV}.$$

Where the value of $k = 8.617 \times 10^{-5} \text{ eV K}^{-1}$.

16.10 STANDARD RESULTS

The standard value of energy band gap is given in the sample available in the lab.

16.11 PERCENTAGE ERROR

$$\% \text{ Error} = \frac{|\text{observed value} - \text{standard value}|}{\text{standard value}} \times 100 \%$$

16.12 PRECAUTION AND SOURCE OF ERROR

- There should be no disturbance near the experiment setup.
- The resistivity of the material should be uniform in the area of measurement.
- The surface on which the probes are at rest should be flat with no surface leakage.
- The diameter of the contact between the metallic probes and the semiconductor crystal chip should be small compared to the distance between the probes.
- Plates should be clean and parallel to each other.
- Reading should be taken carefully.
- Sensitive millivoltmeter and sensitive milliammeter should be used. The surface of the semiconductor should be flat.
- All the four probes should be collinear.

- The adjustment of 4-point probes should be done gently, as the semiconductor chip is brittle.
- The voltages should be measured using inner probes only using a high impedance millivolt meter.
- Temperature of the ovens should not exceed the limits set by manufacturer of the probes and chip set.
- There should not be any fluctuation on the power supply.

16.13 VIVA-VOCE QUESTION AND ANSWERS

Question 1: What is energy band gap?

Answer: It is the energy gap between the valence and conduction band of the Crystal.

Question 2: How do you differentiate between a conductor, insulator and a semiconductor in relation to energy gaps.

Answer: In conductors the valence and conduction bands overlap each other, in insulators there is large energy band gap between valence and conduction bands while in semiconductor this energy band gap is not too large so that at room temperature the thermal energy gained by some of the electrons in the valence band is sufficient to make them jump to conduction band crossing this energy gap.

Question 3: Do you know about intrinsic and extrinsic semiconductor?

Answer: A pure or natural semiconductor is called an intrinsic semiconductor e.g., Silicon and Germanium. But it has small electrical conductivity. In order to increase the conductivity when some pentavalent (like arsenic) or trivalent (like Boron or aluminum) impurity is added to it then it is called an extrinsic semiconductor.

Question 4: Why does a semiconductor behaves as an insulator at zero-degree kelvin?

Answer: At zero kelvin electrons in valence band do not have sufficient energy to cross the energy band gap so as to reach the conduction band and to make themselves available for conduction of electricity. Thus at 0K, semiconductor behaves as an insulator.

Question 5: What is the advantage of four probe method over other methods of measuring resistivity?

Answer: In most of other methods the current carrying contact injects minority carriers which ultimately modify the resistance of the material.

Question 6: What is the band gap for semiconductor?

Answer: This should be around 1 eV. However higher energy band gap up to 2eV has some other advantages to make LED etc.

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EXPERIMENT 17: DETERMINATION OF 'g' BY LINEAR AIR TRACK

Structure

- 17.1 Objectives
- 17.2 Introduction
- 17.3 Apparatus Used
- 17.4 Theory and Formula Used
- 17.5 About apparatus
- 17.6 Procedure
- 17.7 Observation
- 17.8 Calculation and Discussion
- 17.9 Result
- 17.10 Standard Result
- 17.11 Percentage error
- 17.12 Precaution and source of error
- 17.13 Viva-voce questions and Answers
- 17.14 References

17.1 OBJECTIVES:

After performing this experiment, you should be able to understand

- What is linear air track?
- What is acceleration due to gravity?
- What are laws of motion?
- What is force of gravity and how it is responsible for motion of object?
- How does the acceleration on the linear air track depend on inclination of linear air track?
- What are the components of linear air track experimental setup?
- What principle is involved in this experiment?
- How to determine acceleration due to gravity 'g' by motion in a linear air track method.

17.2 INTRODUCTION:

In the beginning of the 17th century, Galileo experimentally examined the concept of acceleration. One of his goals was to learn more about freely falling objects. Unfortunately, his timing devices were not precise enough to allow him to directly study free fall. Therefore, he decided to limit the acceleration by using fluids, inclined planes, and pendulums. In this lab exercise, we will see how the acceleration of a cart sliding on a frictionless inclined plane depends on the ramp angle. If the angle of an incline with the horizontal is small, a cart rolling down the incline moves slowly and its position can be easily measured. Using time and position data, it is possible to calculate the acceleration of the cart. As the angle of the incline is increased, the acceleration also increases. Rather than measuring time, as Galileo did, we will use a motion detector to determine the position and velocity of a glider. We will be able to decide for our self whether the extrapolation to large angles is valid or not. We will also use the air track to study the motion of a mass under a constant force to verify Newton's second law of motion. An air track is one of the most fundamental components of the physics lab. Its near-frictionless surface gives students hands-on experience with the basic concepts of velocity, acceleration, momentum, collisions, and conservation of energy. It was invented in the mid-1960s at the California Institute of Technology by Prof. Nehr and Leighton. It was first presented by them at a meeting of the American Physical Society in NYC in 1965. In this experiment we can use air track to determine acceleration due to gravity whose details is in section 17.4.

17.3 APPARATUS USED:

A linear air track, blower, trolley, two light gates or photo-gate with timer, QED unit and power supply, stopwatch, laboratory jack, wooden blocks, Air track with compressor, Standard issue meter stick.

17.4 THEORY AND FORMULA USED:

Newton's first law of motion states that: if no net force acts on an object, the velocity of the object remains unchanged. The second law, on the other hand, deals with what happens when a net force does act on an object. This law of motion describes the behavior of everything that changes its motion due to a net force such as the trajectory of a baseball or the orbital motion of a planet. While a net force acts on an object, the velocity of the object changes –in other words, it accelerates. When more force is applied, the greater force produces a greater acceleration. Newton's second law states that the acceleration is directly proportional to the net force acting on the object and is in the same direction as the net force. Newton's second law also states that the acceleration is inversely proportional to the mass if force acting on it is constant. To describe motion of an object under uniform acceleration we can use Newton's equations of motion, which are,

$$V_f = V_i + a t \quad \text{----- (17.1)}$$

$$s = x_f - x_i = V_i t + \frac{1}{2} a t^2 \quad \text{----- (17.2)}$$

$$V_f^2 = V_i^2 + 2 a s \quad \text{----- (17.3)}$$

From the diagram figure 17.1, force of gravity can be resolved into two components one is along parallel to the track $F_p = mg \sin \theta$ and another transverse to the track $F_t = mg \cos \theta$, the force of the air lifting F_a equals and cancels the force at the normal to the track F_t . The remaining forces is parallel with the track down the slope F_p . Knowing the Force of gravity acting down the slope and knowing the mass of the glider, use the formula $F=ma$ to determine the expected acceleration down the slope due to gravity. Which is $a = g \sin \theta$.

An air track is a scientific device used to study motion in low friction environment. Its name comes from its structure: air is pumped through a hollow track with fine holes all along the track that allows specially fitted air track cars to glide relatively friction-free. Air tracks are usually triangular in cross-section. Carts which have a triangular base and fit neatly on to the top of the track are used to study motion in low friction environments. We can use a motion detector (photogates) to

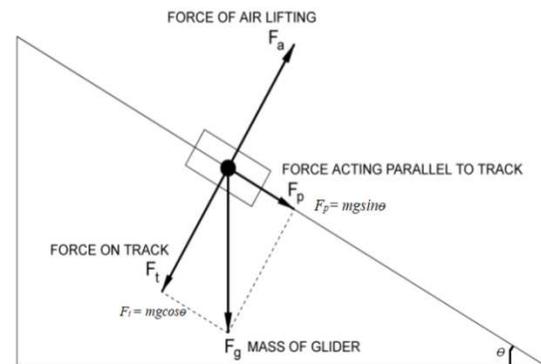


Figure 17.1: diagram of motion in a frictionless inclined plane

determine the position and velocity of a glider. The track can be used to calculate the force of gravity when placed at an angle θ as shown in figure 17.2.

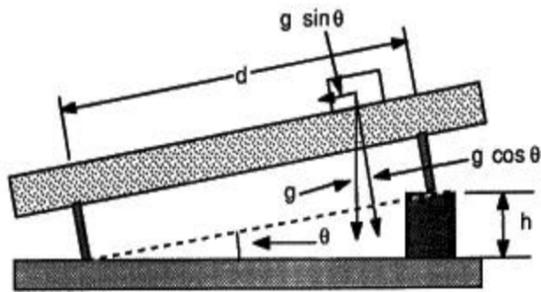


Figure 17.2: motion in a frictionless inclined plane with inclination an angle θ

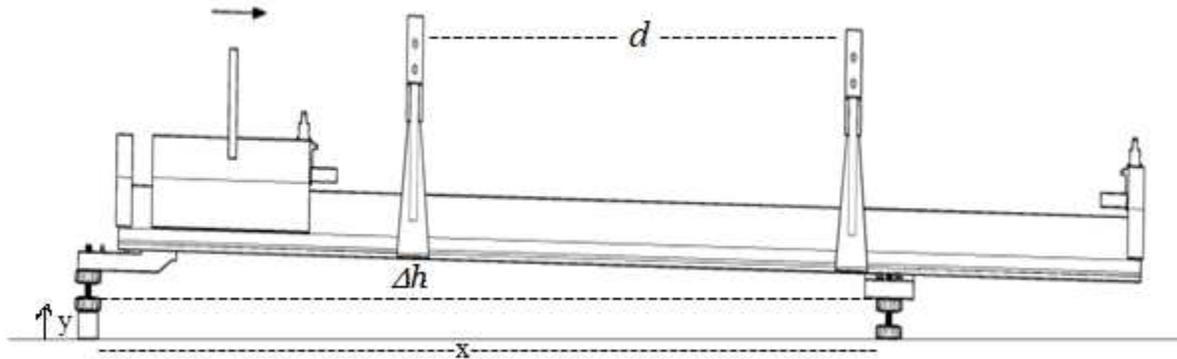


Figure 17.3: The air track adjustment with a glider and two photogate position at some inclination.

The acceleration due to gravity ‘g’ can be determined using equation 17.2. If we release a glider on the frictionless air track as shown in figure 17.3 from the position of the first photogate with $V_i = 0$ (from rest) and calculate the time ‘t’ to pass from the first photogate to the second photogate, then putting $s=d$ and $V_i = 0$, in equation 17.2,

$$s = x_f - x_i = V_i t + \frac{1}{2} a t^2 \text{ becomes, } d = \frac{1}{2} a t^2 \text{ therefore,}$$

$$a = 2 \frac{d}{t^2} \text{----- (17.4)}$$

However, the value of acceleration due to gravity from motion in an inclined plane (see figure 17.1) is $a = g \sin \theta$ where, $\sin \theta = \frac{h}{d}$ (see figure 17.2). We can write,

$$a = g \sin \theta = g \frac{h}{d} \text{----- (17.5)}$$

Comparing equation {17.4} and {17.5}, we can get acceleration due to gravity in terms of ‘h’, ‘d’ and ‘t’ which is,

$$g = \frac{2}{h} \left[\frac{d}{t} \right]^2 \text{----- (17.6)}$$

If the elevation given to the air track is $\sin \theta = \frac{y}{x}$ (see figure 17.3). Then equation {17.5} becomes,

$$a = g \sin \theta = g \frac{y}{x} \text{----- (17.7)}$$

If the leveling screws are at the extreme ends of the air track then to make an inclination we can substitute $y=h$ and $x=L$ (length of the air track). Hence equation {17.6} can be re-written as,

$$g = 2 \frac{L}{h} \frac{d}{t^2} \text{-----} \quad (17.7)$$

This equation {17.7} will help us to get value of acceleration due to gravity in an inclined plane with inclination $\sin\theta = \frac{h}{L}$, where 'h' is the height of one end w. r. t. other end and 'L' is the length of the track between these two ends. However 'd' is the distance between two photogates for which a glider can slide within time 't' from first photogate to second starting from rest on a frictionless track.

17.5 ABOUT APPARATUS:

Air track apparatus is shown in figure 17.4, which consists of a long air track (air is pumped through a hollow track with fine holes all along the track that allows specially fitted air track cars to glide relatively friction-free), a glider, trolley, two light photo-gate with timer, QED unit and power supply, stopwatch/digital display, laboratory jack, wooden blocks, air compressor and Standard meter stick. A glider released from rest maintained the same weight throughout each trail. The same amount of air should be pushed through the air track at same pressure. Photogates are the same distance apart. Use banana plug cables to loop the power from the first Gate's light source to the second Gate. Use two more cables to connect the second Gate signal to the Stop sockets on the timer. Use the Function button on the timer to select Start/Stop mode. This means that the glider or front edge of the flag entering the first gate will start the timer and the same front edge of the flag or glider entering the second gate will stop the timer. To repeat the experiment, press stops, reset the timer to zero in the display and set the next mode.

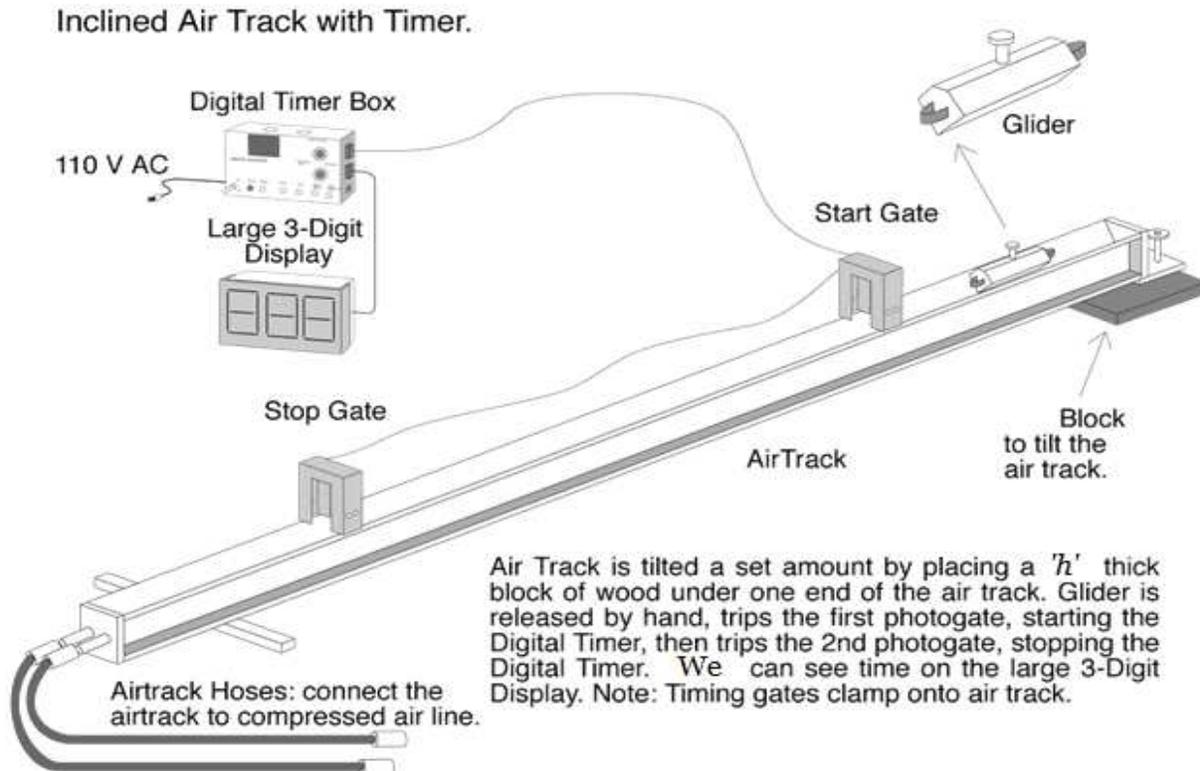
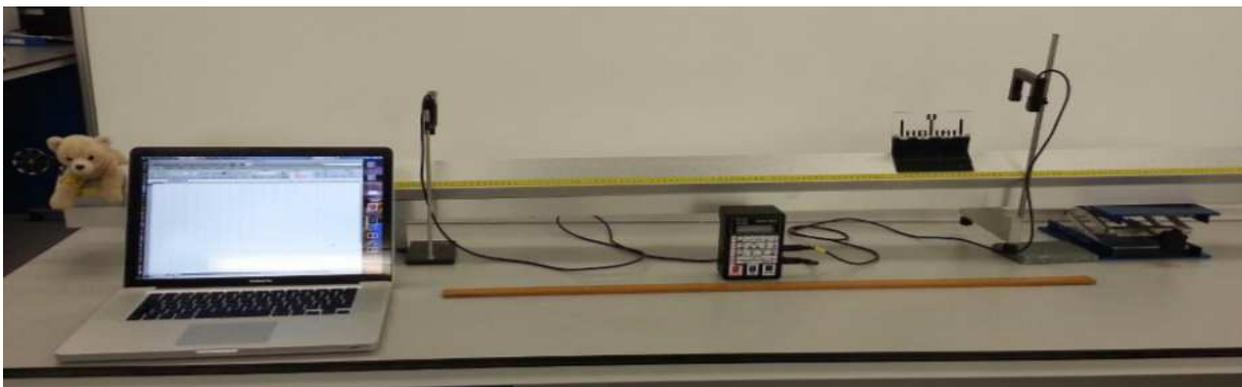


Figure 17.4: An air track experimental setup with photogates and digital timer display.

The timer will show the time taken by glider to move between two photogates. Using the scale along the length of the air track, measure the distance between the centers of the two gates and use equation {17.4} to measure the acceleration. The value of acceleration due to gravity from motion in inclined plane can be measure using equation {17.7} after measuring the inclination of the airtrack. This experiment can be done gently by precise measurement of time of motion of glider between two photogates using stopwatch in the absence of digital timer and QED. Using the technological advancement one can use a software based timer with auto LED photogates.



*Figure 17.5: experimental arrangement of Air track in a lab.***17.6 PROCEDURE**

Refer to figure (17.3) and figure (17.4), we have to follow the following steps:

1. Set up the air track by connecting the air compressor to the track using the hose.
2. Place a glider on the track and get ready to turn on the compressor.
3. Adjust the supporting legs so that the air track is levelled. When the track is level the glider should be able to remain stationary.
4. A level starting position ensures that the angle that is introduced per the laboratory procedure is the only change in angle.
5. Elevate one end of the track with the wooden block. Measure the height, 'h', of the block and the distance, 'L', between the support legs.
6. Using the values of h and L , calculate elevation of the track, $\sin \theta = \frac{h}{L}$.
7. The photo-gate timer will measure how long glider takes to pass through two photogates.
8. We can attach the flag or nail to the top of the glider to record the time to pass through photogates but making sure the flag's width is parallel to the length of glider.
9. Set up the photogate timer by setting the timer to GATE mode which means that it will measure the time to pass between two photogates.
10. Record the distance between two photogates, it is the displacement 'd'.
11. Place a glider on the track and turn on the compressor.
12. Hold glider at rest at first photogate and release it for motion.
13. The smart timer is turned on, connected to the photogates and set to record the time taken for the glider to travel between the photogates. This will provide value of time 't'.
14. Using equation {17.7}, calculate the value of 'g'.
15. The red LED on top of the photogate shows when the gate is blocked. You will need to re-adjust the gate as you move the photogate timer along the track. Make sure the gate is perpendicular to the air track.
16. Place a glider on the track and get ready to turn on the compressor.
17. Release the glider from the position of first photogate and record the time for the glider to pass through the second photogate using timer.
18. Record the time three times for this distance.
19. The glider must be released from rest each time.
20. Calculate the slope angle by using $\sin \theta = h/d$. Then using vectors and the value of the various slope angles to determine what proportion of the forces due to gravity are acting down the slope.
21. Repeat the process for different values of inclination and different position of photogates so that an average value of measurement will be more accurate and précises.

17.7 OBSERVATION

Observation for the measurement of time taken by glider to travel between two photogates (using timer or stop watch) on a frictionless air track of length 'L' is in table 1.

Table 1: Time of travel between two photogates, when glider released from first photogate.

S. No.	Elevation of air track 'h' (mm)	Distance between two Photogates 'd' (mm)	Time 't' taken by glider to travel between two Photogates (sec)				Acceleration $g = 2 \frac{L}{h} \frac{d}{t^2}$	Mean value of 'g' (mm/s ²)
			Trial 1	Trial 2	Trial 3	Average		
1								
2								
3								
--								
--								
--								
--								
--								

Calculate the slope angle by using $\sin\theta = (h/L)$. Then using vectors and the value of the various slope angles to determine what proportion of the forces due to gravity are acting down the slope. Using the observation of table 2, we can also plot the graph between acceleration 'a' and 'sin θ '.

Table 2: Observation table to observe acceleration and elevation of air track.

S. No.	Elevation of air track 'h' (mm)	Distance between two Photogates 'd' (mm)	Time 't' taken by glider to travel between two photogates (sec)				Acceleration $a = 2 \frac{d}{t^2}$	sin $\theta = h/L$
			Trial 1	Trial 2	Trial 3	Average 't'		
1								
2								
3								

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--								
--								
--								
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17.8 CALCULATION AND DISCUSSION

We can calculate the following values to fill table 1 and table 2 from above observation.

- (i) Height of elevation of air track ‘h’ =mm
- (ii) Length of track between leveling screw ‘L’ =mm
- (iii) Distance between two photogates ‘d’ =mm
- (iv) Time taken by glider between the gates ‘t’ =sec
- (v) Acceleration of glider along the air track ‘a’ =mm/s²
- (vi) The mean value of acceleration due to gravity ‘g’ =mm/s²
- (vii) Sin θ of elevation of air track (h/L)=

We can draw a graph between acceleration *a* and *sin θ* as shown in the figure 17.8. From the graph the value of acceleration due to gravity ‘g’ is equal to the slope of the graph. (Use appropriate scale in the graph).

$$m = \tan \theta = g = \frac{a}{\sin \theta} = \frac{CB}{AB}$$

g=mm/s².

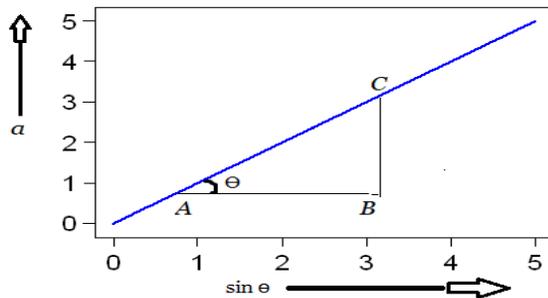


Figure 18.8: Graph between acceleration *a* and *sin θ* of angle of elevation of air track.

17.9 RESULTS

The value of acceleration of gravity is equal to..... mm/s².

17.10 STANDARD RESULTS

The standard value of acceleration due to gravity is = mm/s² or 9.8 m/s².

17.11 PERCENTAGE ERROR

$$\% \text{ Error} = \frac{|\text{observed value} - \text{standard value}|}{\text{standard value}} \times 100 \%$$

Observational error analysis can be solved by given formula:

$$\text{Error analysis: } = \frac{\Delta g}{g} = \sqrt{\left(\frac{\Delta h}{h}\right)^2 + \left(2\frac{\Delta d}{d}\right)^2 + \left(2\frac{\Delta t}{t}\right)^2}$$

17.12 PRECAUTION AND SOURCE OF ERROR

- Air track must be in level before starting the experiment and ensure that it is friction free.
- Air track should be in translational and rotational equilibriums before starting the experiment.
- When the track is leveled, the glider should remain stationary
- Measurement of time should be in good accuracy. Gently switch on the GATE of the timer.
- The glider must be released from rest each time.
- Observations can be made repeatedly to get the accuracy in average by increasing the trail.
- While elevating the air track from one end, ensures that the angle that is introduced per the laboratory procedure is the only change in angle. There should not be any rotational change.
- Elevation should be given slowly-slowly in steps.
- Distance between the photogates should be larger as compared to elevation height h.

17.13 QUESTION VIVA-VOCE AND ANSWERS

Question 1: What do you mean by gravity?

Answer: The property of the earth by virtue of which it attracts the bodies towards its center, is known as gravity.

Question 2: What is acceleration due to gravity? How is it defined?

Answer: Acceleration due to gravity is numerically equal to the force of attraction with which a unit mass is attracted by the earth towards its centre.

Question 3: What are the units and dimensions of 'g'?

Answer: The units and dimensions of accelerations due to gravity are cm per sec² and LT⁻² respectively.

Question 4: What is Newton's second law of motion?

Answer: Newton's second law states that the acceleration is directly proportional to the net force acting on the object and is in the same direction as the net force. Newton's second law also states that the acceleration is inversely proportional to the mass if force acts on it constant.

Question 4: Why is it important to first level the air track?

Answer: Leveling of air track is important to ensure the one-dimension motion of glider along the track.

Question 5: Why we record the time in various trails for the same distance at same inclination?

Answer: To reduce the observational error.

Question 6: Why we use a longer air track to do this experiment?

Answer: It is because of measurement of time between two photogates which are apart, reduces the error in the measurement of time.

Question 7: Can we do this experiment using stop watch rather than using timer and photogates?

Answer: Yes, but for reducing the error in the measurement, we can use a longer track and reduces reaction time to switch on and off the watch.

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EXPERIMENT 18: THERMAL CONDUCTIVITY BY LEE'S DISC METHOD

Structure

- 18.1 Objectives
- 18.2 Introduction
- 18.3 Apparatus Used
- 18.4 Theory and Formula Used
- 18.5 About apparatus
- 18.6 Procedure
- 18.7 Observation
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- 18.9 Result
- 18.10 Standard Result
- 18.11 Percentage error
- 18.12 Precaution and source of error
- 18.13 Viva-voce questions and Answers
- 18.14 References

18.1 OBJECTIVES:

After performing this experiment, you should be able to understand

- What is thermal conduction?
- What is thermal conductivity?
- What is coefficient of thermal conductivity?
- What is steady state?
- What are good and bad conductor of heat?
- What are specific heat and its importance to define thermal conductivity?
- What are Lee's apparatus and the experimental specimen in the form of a disc?
- What principle is involved in this method?
- How to determine thermal conductivity of a bad conductor (glass, cardboard, etc) in form of a disc using Lee's method.

18.2 INTRODUCTION:

Thermal property is the important material property for engineering and analysis of insulating materials. Thermal conductivities of insulating materials are determined by various techniques in practical lab and compared with the literature values. Lee's apparatus is used to measure this property of insulating materials by steady state technique. This apparatus gives more precise result for insulators that can be utilized for the further thermal related analysis. This experimental set up is to determine and analyze thermal conductivities of insulating materials. The term thermal insulation can refer either to materials used to reduce the rate of heat transfer, or the methods and processes used to reduce heat transfer. Heat energy can be transferred by conduction, convection, radiation. Thermal insulation prevents heat from escaping a container or from entering a container. In other words, thermal insulation can keep an enclosed area such as a building warm, or it can keep the inside of a container cold. Insulators are used to minimize that transfer of heat energy. Insulation is a material that provides a high resistance to heat flow. Examples are foamed plastics, mineral or glass fibers, cork, and foamed glass. The Lee's Disc experiment determines an approximate value for the thermal conductivity K of a poor conductor like glass, cardboard, etc.

18.3 APPARATUS USED:

Lee's apparatus and the experimental specimen in the form of a disc, two thermometers, stop watch, weighing balance, Special lamp stand, Boiler and Heater.

18.4 THEORY AND FORMULA USED:

Thermal conductivity is the intrinsic property of a material which relates its ability to conduct heat. Heat transfer by conduction involves transfer of energy within a material without any

motion of the material as a whole. Conduction takes place when a temperature gradient exists in a solid (or stationary fluid) medium. Conductive heat flow occurs in the direction of decreasing temperature because higher temperature equates to higher molecular energy or more molecular movement. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide. Thermal conductivity is defined as the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area due to a unit temperature gradient under steady state conditions and when the heat transfer is dependent only on the temperature gradient. Fourier's law expresses conductive heat transfer as

$$H = K A \frac{T_2 - T_1}{x} \quad \text{----} \quad (18.1)$$

Where H is the steady state rate of heat transfer, K is the thermal conductivity of the sample, A is the cross sectional area and $(T_2 - T_1)$ is the temperature difference across the sample thickness 'x' (see Fig. 18.1), assuming that the heat loss from the sides of the sample is negligible. To keep the loss from the sides' small, the sample is made in form of a thin disk with a large cross sectional area compared to the area exposed at the edge. Keeping 'A' large and 'x' small produces a large rate of energy transfers across the sample. Keeping x small also means that the apparatus reaches a steady state (when temperature T_1 and T_2 are constant) more quickly.

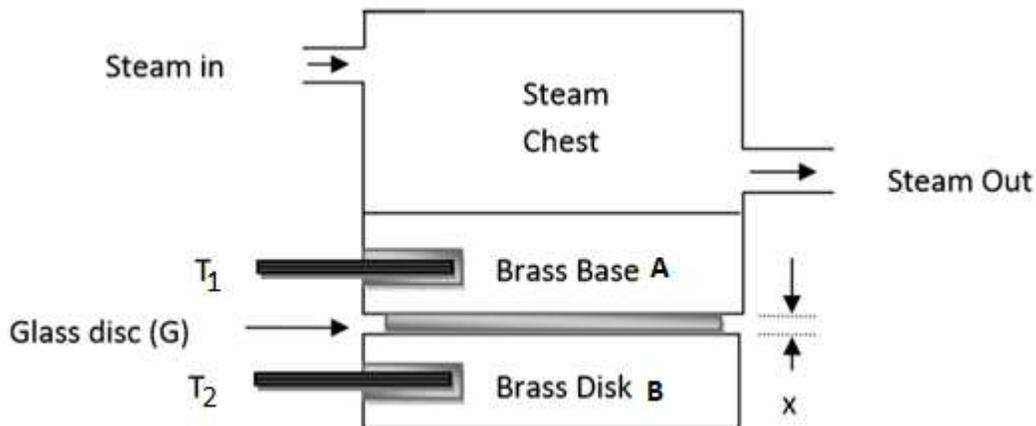
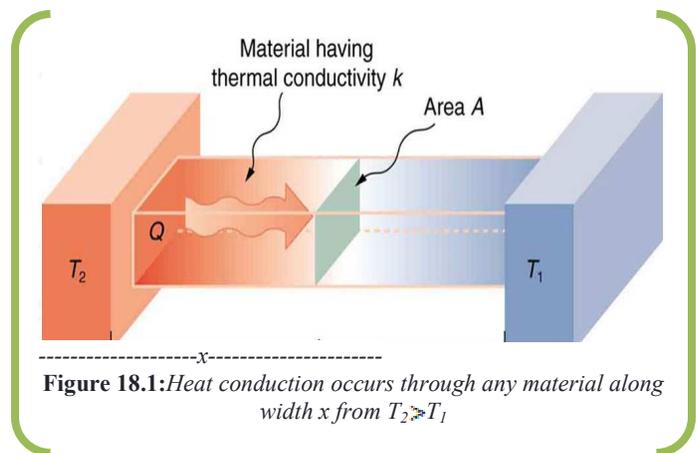


Figure 18.2: Heat conduction through poor conductor glass disc (G) at steady state from $T_1 \gg T_2$

The apparatus shown in Fig. 18.2 consists of two parts. The lower part B is circular metal disc. The experimental specimen G, usually rubber, glass or ebonite (here it is glass/cardboard) is placed on it. The diameter of G is equal to that of B and thickness is uniform throughout. A

steam chamber is placed on B. The lower part of the steam chamber, A is made of a thick metal plate of the same diameter as of B. The upper part is a hollow chamber in which two side tubes are provided for inflow and outflow of steam. Two thermometers T_1 and T_2 are inserted into two holes in A and B, respectively. There are three hooks attached to B. The complete setup is suspended from a clamp stand by attaching threads to these hooks as shown in figure 18.3.

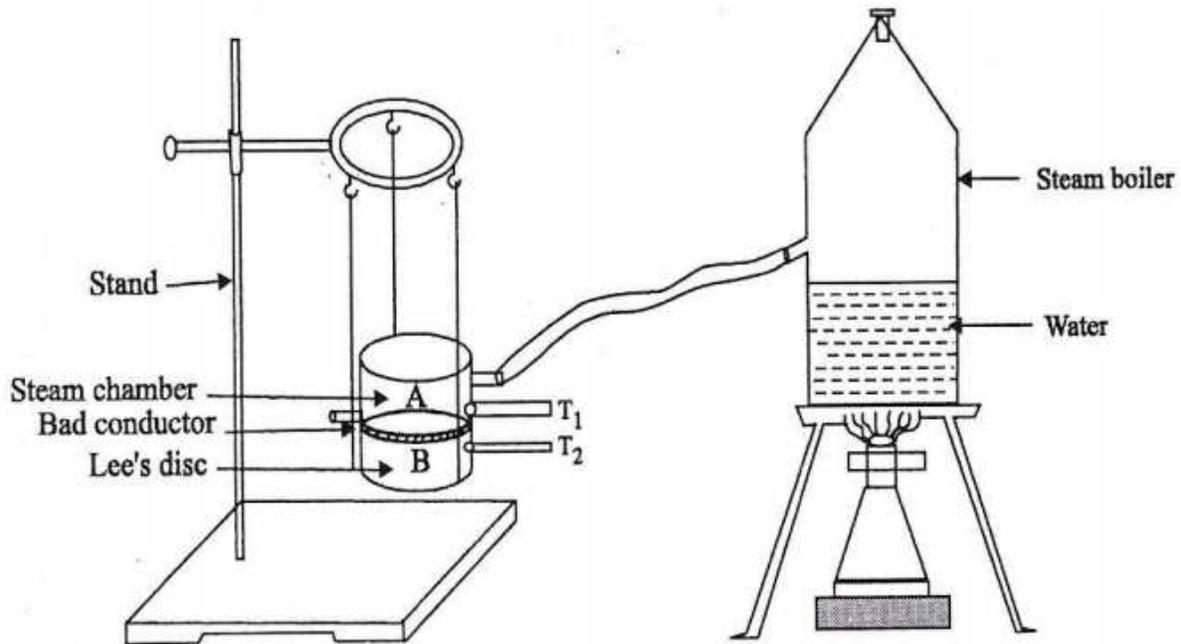


Figure 18.3: Lee's disc apparatus

When steam flows for some time, the temperatures recorded (T_1 and T_2) gradually remain steady. This is the steady state. Let at the steady state, temperature of A is T_1 , Temperature of B is T_2 , Surface area of G is $A = \pi r^2$, Conductivity of G is K and Thickness of sample G is x . Hence amount of heat flowing through G per second, H is given by Eq. (18.1). When the apparatus is in steady state (temperatures T_1 and T_2 constant), the rate of heat conduction into the brass disc B is equal to the rate of heat loss from the bottom of it. The rate of heat loss can be determined by measuring how fast the disc B cools at the previous (steady state) temperature T_2 (with the top of the brass disc covered with insulation). If the mass and specific heat of the lower disc B are m and s , respectively and the rate of cooling at T_2 is (dT/dt) then the amount of heat radiated per second is,

$$H = m s \frac{dT}{dt} \dots \dots \dots (18.2)$$

Equating (8.1) and (18.2) and simplifying, K can be determined as,

$$H = K A \frac{T_1 - T_2}{x} = m s \frac{dT}{dt} \dots \dots \dots (18.3)$$

Which gives $K = \frac{m s \frac{dT}{dt}}{A \frac{T_1 - T_2}{x}} \dots\dots\dots (18.4)$

$$K = \frac{m s x}{A (T_1 - T_2)} \cdot \left[\frac{dT}{dt} \right] \dots\dots\dots (18.5)$$

This equation is useful to determine the value of conductivity for a bad conductor of heat at steady state conduction.

18.3 ABOUT APPARATUS:

Lee's disc apparatus is shown in figure 18.3, it consists of an experimental specimen (disc of a bad conductor material having radius equal to the good conductor metal discs) in the form of a disc, Two thermometers, Stop watch, Weighing balance, Special lamp stand, Boiler and Heater. The specimen disc made of the poor conductor, radius r and thickness x is kept between a steam chamber and good conductivity metal discs (of the same metal). The lower part of the steam chamber is made of a thick metal plate of the same diameter as of specimen. The upper part is a hollow chamber in which two side tubes are provided for inflow and outflow of steam. It has inlet and outlet tubes for steam. In addition, it has radial holes to insert thermometers. Two thermometers T_1 and T_2 are inserted into two holes, one is in steam chamber and other is in good conductor disc above which specimen is kept. The complete setup is suspended from a clamp stand by attaching threads to these hooks as shown in figure 18.4.

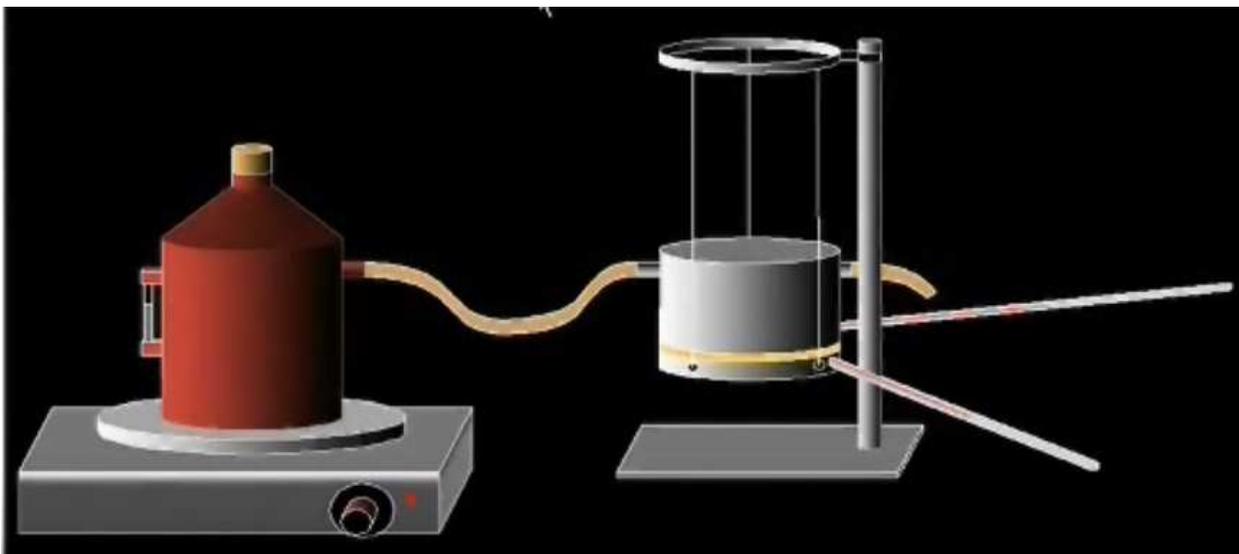


Figure 18.4: picture of setup of Lee's disc apparatus

Thermal conductivity is the property of a material. It indicates the ability of a material to conduct heat. When steam is passed through the cylindrical vessel a steady state is reached

soon. At the steady state, heat conducted through the bad conductor is equal to heat radiated from the Lee's disc B as shown in figure 18.3. Steam from boiler is allowed to pass from one end of steam chamber which comes out from other end. Steam is allowed to pass till the setup comes to equilibrium, so that the heat lost by the lower disc to convection is the same as the heat flow through the poorly conducting disc.

18.4 PROCEDURE

Refer to figure (18.3) and figure (18.4), we have to follow the following steps:

1. Fill the boiler with water to nearly half and heat it to produce steam.
2. In the meantime, take weight of B by a weighing balance and note down its mass.
3. Note its specific heat of the material of lee's disc from a constant table (known).
4. Measure the diameter (half of it is the radius 'r') of the specimen by a suitable scale or slide calipers, if possible.
5. Calculate the surface area, $A = \pi r^2$.
6. Measure the thickness 'x' of the specimen by screw gauge.
7. Take observations at 5 spots and take the mean value for measuring 'x'.
8. Put the disc, specimen, steam chamber etc. in position and suspend it from the clamp stand as shown in figure 18.3. Insert the thermometers.
9. Check if both of them are displaying same readings at room temperature. If not, note the difference θ , is to be added to $(T_1 - T_2)$ later.
10. Now stem is ready. Connect the boiler outlet with the inlet of the steam chamber by a rubber tube.
11. Temperatures recorded in the thermometers will show a rise and finally will be steady at T_1 and T_2 .
12. Wait for 10 minutes and note the steady temperature. Stop the inflow of steam.
13. To measure $\left[\frac{dT}{dt}\right]$, Remove the specimen disc G and put steam chamber directly in the contact of the Lee's disc B.
14. Heat B directly by the steam chamber till its temperature is about $T_2 + 10^\circ\text{C}$.
15. Remove the steam chamber, the disc B is then suspended separately and allowed to cool.
16. Wait for 1 - 2 minutes so that heat is uniformly distributed over the disc B.
17. Now its temperature is noted at regular interval of time in thermometer T_2 . Place the insulating material on B. Start recording the temperature at $\frac{1}{2}$ minute intervals.
18. Continue till the temperature falls by 100 from T_2 .
19. A graph is plotted between temperature and time, which comes out to be a curved line and from the tangent to curve at the temperature T_2 , the rate of fall of temperature $\left[\frac{dT}{dt}\right]$ at T_2 is found.

18.5 OBSERVATION

Observation for the measurement of diameter of specimen disc (using scale/slide calipers) is in table 1.

Table 1: observation of diameter of specimen disc ($d=2r$)

S. No.	Reading for diameter of specimen disc (cm)		Diameter (cm)	Mean value of reading (cm)
	Main scale reading	small scale reading		
1				
2				
3				

Since radius is half of the diameter, therefore radius (r) = $d/2 = \dots\dots\dots$ cm. Observation for the measurement of thickness of specimen disc is in table 2. Take observations at 5 different spots and take the mean value for measuring 'x'.

Table 2: observation of thickness of specimen disc (x)

S. No.	Reading for thickness of specimen disc (cm)		Thickness (cm)	Mean value of reading (cm)
	Main scale reading	small scale reading		
1				
2				
3				
4				
5				

Observation table for the temperatures for ascertaining the steady state is given in Table 3.

Table 3: observation for ascertaining the steady state

S. No.	Time in minutes	Reading of thermometer $T_1^\circ\text{C}$	Reading of thermometer $T_2^\circ\text{C}$
1	0	--	--
2	1	--	--
3	2	--	--
4	3	--	--
5	4	--	--
--	--	--	--

From this table, the reading should be taken when steady state is nearly attained. Steady state temperatures from the above observations are

- (i) Steady state for thermometer $T_1 = \dots\dots\dots^\circ\text{C}$
 (ii) Steady state for thermometer $T_2 = \dots\dots\dots^\circ\text{C}$

The rate of fall of temperature $\left[\frac{dT}{dt}\right]$ at T_2 can be observed during the process of cooling of Lee's Disc using observation table 4.

Table 4: observation for $\left[\frac{dT}{dt}\right]$ at T_2 during the cooling of Lee's disc

S. No.	Time			Reading of thermometer $T_2^\circ\text{C}$	$\left[\frac{dT}{dt}\right]$
	Minute	Sec	Total sec		
1	0	10	10	Θ_1	} = $\frac{\Theta_1 - \Theta_2}{t_2 - t_1} =$
2	0	20	20	Θ_2	
3	0	30	30	Θ_3	} = $\frac{\Theta_3 - \Theta_2}{t_3 - t_2} =$
4	1	40	40	Θ_4	} = $\frac{\Theta_3 - \Theta_4}{t_4 - t_3} =$
5	1	50	50	--	
--	1	60	60	--	
	1	10	70		
	1	20	80		

18.6 CALCULATION AND DISCUSSION

We can calculate the following values from above observation.

- (viii) Radius r of the experimental disc = $\dots\dots\dots\text{cm}$
 (ix) Area of specimen disc ($A = \pi r^2$) = $\dots\dots\dots\text{cm}^2$
 (x) Thickness x of the experimental disc = $\dots\dots\dots\text{cm}$
 (xi) Mass m of the Lee's disc B = $\dots\dots\dots\text{cm}$ (use weighing machine)
 (xii) Specific heat s of disc B (use standard value as per the material) = $\dots\dots\dots\text{J}/(\text{kg}\cdot^\circ\text{C})$

We can draw a graph between time and temperature for the disc B as shown in the figure 18.8.

From the graph the value of $\left[\frac{dT}{dt}\right]$ at T_2 is equal to the slope of the curve at T_2 . It is,

$\left[\frac{dT}{dt}\right]$ at $T_2 = \dots\dots\dots^\circ\text{C}/\text{sec}$. Now find out the value of K using Equation 18.5.

$$K = \frac{m s x}{A (T_1 - T_2)} \cdot \left[\frac{dT}{dt}\right]$$

$$= \dots\dots\dots\text{Joule}/\text{cm}^\circ\text{C}/\text{sec}.$$

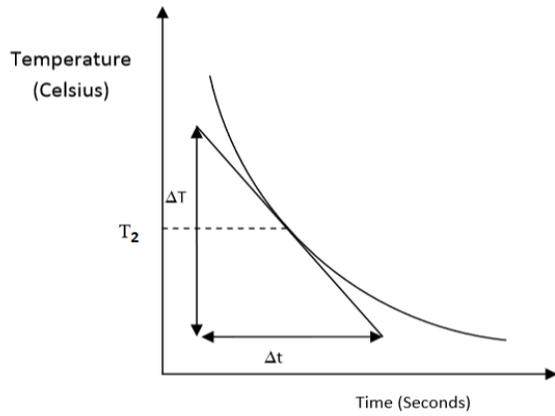


Figure 18.8: Graph between time and temperature for cooling the Lee's disc

18.7 RESULTS

The coefficient of thermal conductivity K of the given non-metallic bad conductor solid is equal to..... Joule/cm $^{\circ}$ C/sec.

18.8 STANDARD RESULTS

The standard value of thermal conductivity $K = \dots\dots$ Joule/cm $^{\circ}$ C/sec and it is given for the sample available in the lab.

18.9 PERCENTAGE ERROR

$$\% \text{ Error} = \frac{|\text{observed value} - \text{standard value}|}{\text{standard value}} \times 100 \%$$

Observational error analysis can be solved by given formula:

$$\text{Error analysis: } \frac{\Delta k}{k} = \sqrt{\left(\frac{\Delta\left(\frac{dT}{dt}\right)}{\frac{dT}{dt}}\right)^2 + \left(2\frac{\Delta d}{d}\right)^2 + \left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta T_2 + \Delta T_1}{T_2 - T_1}\right)^2}$$

18.10 PRECAUTION AND SOURCE OF ERROR

- Observation for radius and thickness of specimen disc should be taken before starting the experiment.
- The experimental disc should be thin to avoid edge loss.
- The steady state should be obtained very accurately.
- Don't record T_1 and T_2 unless they have remained steady for at least 10 minutes.
- The tangent to the cooling curve should be done very carefully. An error in (dT/dt) will result in a wrong result for k .
- The radiation loss only due to the surface of G in contact with B is taken into account here while there is some loss at the edges. Therefore, the diameter of the specimen disc G should be sufficiently large than its thickness.
- Since room temperature might change during the course of the experiment, it is advised to complete the experiment quickly.

18.11 VIVA-VOCE QUESTION AND ANSWERS

Question 1: Define coefficient of thermal conductivity.

Answer: It is the quantity of heat flowing per second through unit area of cross section of an element of material, of unit thickness, when the difference of temperature between its faces is unity.

Question 2: What is the unit of coefficient of thermal conductivity?

Answer: The unit is Calorie per centimeter per degree centigrade per second or joule per centigrade per centimeter per degree centigrade per second.

Question 3: How is the heat transfer or transmitted in this Experiment?

Answer: By conduction.

Question 4: What is steady state in thermal conduction?

Answer: In steady state, the temperature of each point of conductor becomes constant, i.e., it does not rise further. The heat transmitted from one section to another does not raise their temperature but a part of it is radiated and rest transmitted to next section. In steady state the temperature of a point on the conductor is a function of its distance from the hot end and does not depend on time.

Question 5: Why is the experimental material taken in the form of a thin disk?

Answer: A thin disk is taken because its area of cross section is large, while thickness is small. It increases the quantity of heat conducted across its faces.

Question 6: Why are the two discs, between which the disk of bad conductor is pressed, taken of same metal?

Answer: It ensure the normal flow of heat from one face of experimental disk to another face.

Question 7: What principal is involved in this method?

Answer: In steady state, Temperature of lower metal plate becomes constant and then the heat lost by it to the surroundings it just made up by the heat gained by it through the experimental disc of bed connector.

Question 8: At what temperature, do you find rate of radiation?

Answer: At steady state temperature we found rate of radiation.

Question 9: Can this method be used in case of good conductor?

Answer: No, because the two sides of the experimental this will at once acquired the same temperature.

Question 10: Can this method be used in case of liquids?

Answer: With liquids, the difficulty is that the convection currents are easily set up and transfer more heat than the conduction actually does. To overcome this difficulty, liquid should be heated at the top and should be taken in the form of thin film.

18.12 REFERENCES

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