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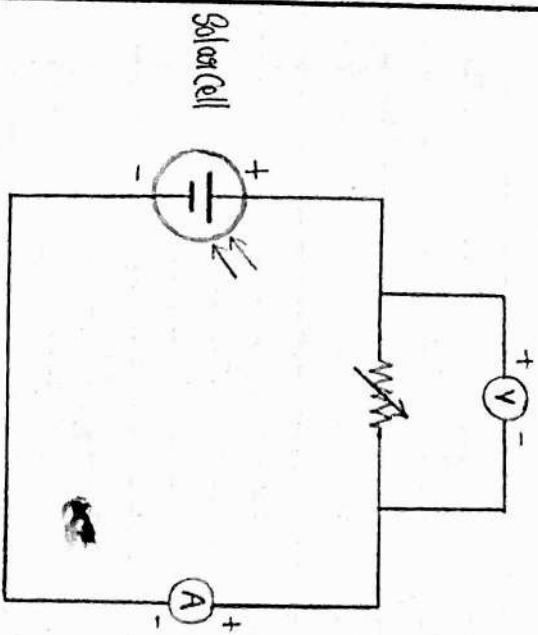
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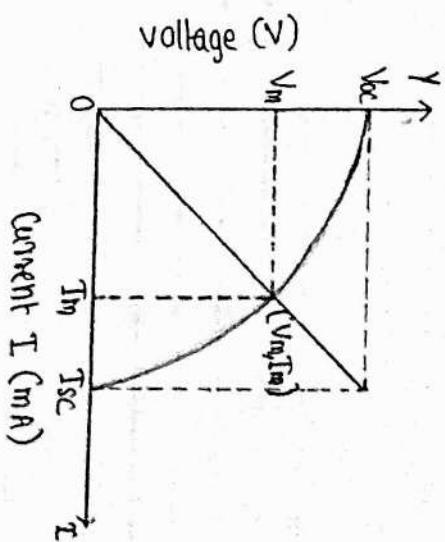
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CIRCUIT DIAGRAM



I-V CHARACTERISTICS



EXPERIMENT 1

DATE - 10/09/2023

SOLAR CELL - EFFICIENCY & FILL FACTOR

AIM

To plot the $V-I$ characteristics of the solar cell and hence determine the fill factor and efficiency.

APPARATUS REQUIRED

Solar cell, Light source, Resistance box, multimeter, connecting wires

THEORY

The solar cell is a semiconductor device which converts the solar energy into electrical energy. It is also called a photo voltaic cell. A solar panel consists of numbers of solar cells connected in series or parallel. The number of solar cells connected in a series generates the desired output voltage and connected in parallel generates the desired output current. The conversion of solar energy into electric energy takes place only when the light is falling on the cells of the solar panel. A solar cell operates in somewhat the same manner as other junction photo detectors. A built-in depletion region is generated in that without an applied reverse bias and photons of adequate energy break hole-electron pairs. When a load is

OBSERVATIONS

Distance between solar cell and light source = 36.5 cm

A. CHARACTERISTICS

Load resistance R_L (Ω)	Voltage (V)	Current I (mA)
0	0	2.45
100	0.25	2.47
200	0.50	2.46
300	0.76	2.46
400	1.01	2.48
500	1.21	2.47
600	1.43	2.47
800	1.72	2.44
1000	1.73	2.45
2000	1.86	2.10
3000	2.21	1.57
4000	1.22	1.22
5000	1.24	1.00
6000	1.26	0.84
7000	1.27	0.73
8000	1.28	0.64
9000	1.29	0.57
10,000	1.31	0.52
20,000	1.32	0.26
00	1.38	0

connected across the cell, the potential causes the photo-current to flow through the load. The emf generated by the photo-voltaic cell in the open circuit i.e., when no current is drawn from it is denoted by V_{oc} , called open circuit voltage. This is the maximum value of emf. When a high resistance is introduced in the external circuit a small current flows through it and the voltage decreases. The voltage goes on falling and the current goes on increasing as the resistance in the external circuit is reduced. When the resistance is reduced to zero the current rises to its maximum value known as saturation current and is denoted as I_{sc} , the voltage becomes zero. A V-I characteristic of a photo voltaic cell is shown in the figure.

The product of open circuit voltage V_{oc} and short circuit current I_{sc} is known as an ideal power.

$$\text{Ideal power} = V_{oc} \times I_{sc}$$

The maximum useful power is the area of the largest rectangle that can be formed under the $V-I$ curve. V_m and I_m are the values of voltage and current under this condition, then

$$\text{maximum useful power, } P_{max} = V_m \times I_m$$

The ratio of the maximum useful power to ideal power is called the fill factor. Therefore,

$$\text{Fill Factor, } FF = \frac{V_m \times I_m}{V_{oc} \times I_{sc}}$$

Efficiency of solar cell refers to the ratio of energy output from the solar cell to the input energy from the sun, here we are using a incandescent lamp.

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

$$P_{out} = P_{max} = V_m \times I_m$$

$$P_{in} = I A C$$

where I is the irradiance, which is the amount of light energy incident on every square metre of a surface per second.

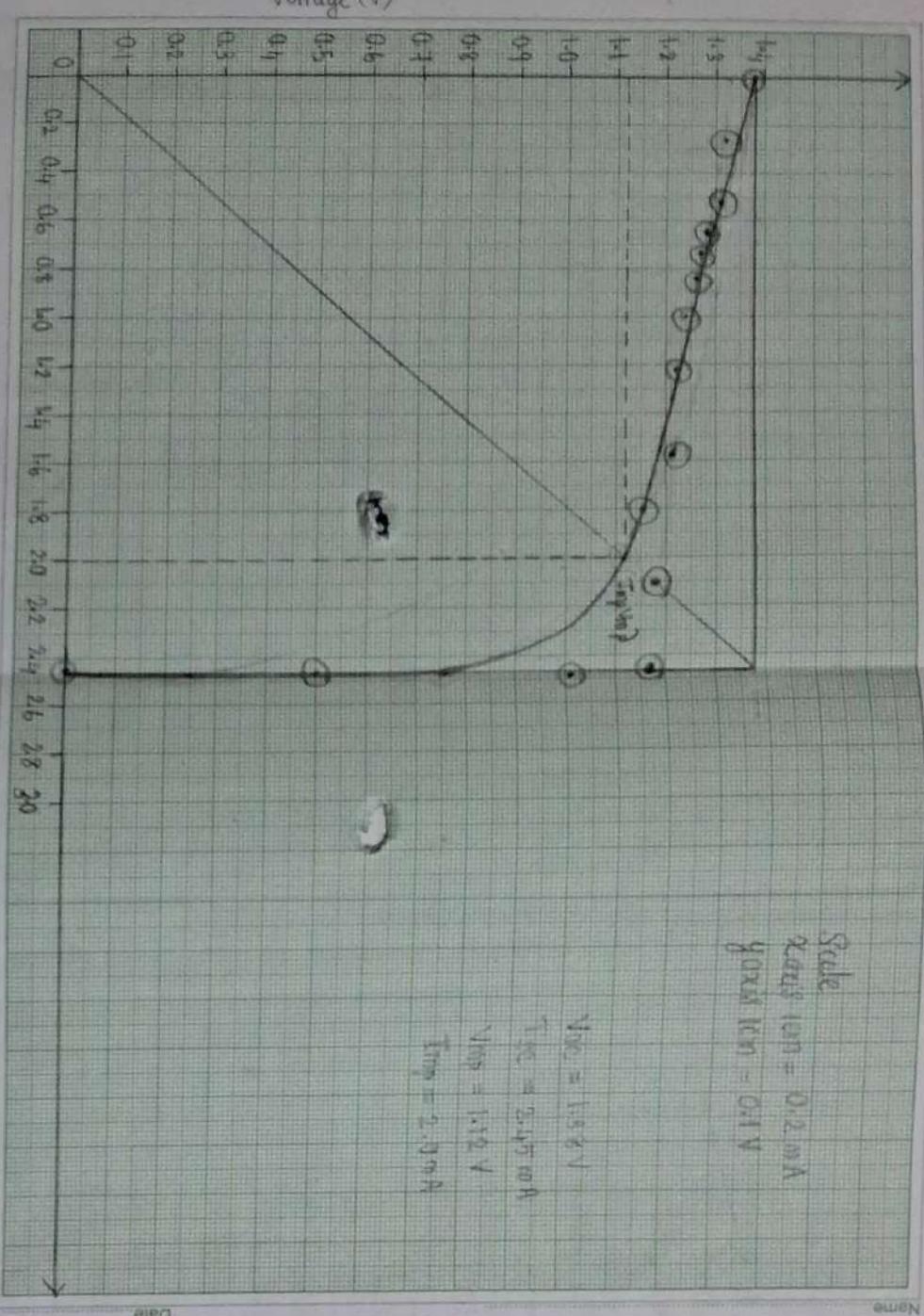
$$\text{Irradiance, } I = \frac{E}{A t} = \frac{P_{source}}{4 \pi d^2}$$

where P - power in watts of the light source
 A - Area of the sphere on which the energy is projected out from the sun.

$d = \sqrt{A / (4 \pi)}$
 where d - distance between light source and solar cell

$$\text{In general, Efficiency } \eta = \frac{V_m I_m}{I A C}$$

$$I = \frac{P_{source}}{4 \pi d^2}$$



$$V_{oc} = 1.98 \text{ V}$$

$$I_{sc} = 2.45 \text{ mA}$$

$$V_m = 1.72 \text{ V}$$

$$I_m = 2.10 \text{ mA}$$

$$\text{Pout}$$

$$P_m$$

$$\Delta x = V_m \times I_m$$

$$A_c$$

Irradiation, which is the amount incident on every square metre of second.

$$I = \frac{E}{A_t} = \frac{P}{A} = \frac{P_{source}}{4\pi d^2}$$

Power in watts of the light source of the sphere on which the energy is projected out from the sun.

where d - distance between light source and solar cell

$$\text{In general, Efficiency } \eta = \frac{V_m I_m}{P_{AC}}$$

$$\eta = \frac{P_{source}}{4\pi d^2}$$

From graph

$$I_{sc} = 2.45 \text{ mA}$$

$$V_{oc} = 1.38 \text{ V}$$

$$I_{mp} = 2.0 \text{ mA}$$

$$V_{mp} = 1.12 \text{ V}$$

$$\text{Fill factor } FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}} = \frac{1.12 \times 2.0 \times 10^{-3}}{1.38 \times 2.45 \times 10^{-3}} \times 100 = \underline{\underline{66.25\%}}$$

The fill factor for silicon devices may vary from 40 to 82%.

Error percentage in fill factor = $\frac{0.70 - 0.6625}{0.70} \times 100$

$$= \frac{0.70 - 0.6625}{0.70} \times 100 = \underline{\underline{5.3\%}}$$

$$\text{Efficiency, } \eta = \frac{P_{out}}{P_{in}} = \frac{V_{mp} I_{mp}}{E_{AC}}, \quad AC = 30 \times 10^4 \text{ m}^2.$$

$$E = \frac{P_{source}}{4\pi d^2}, \quad d = 36.5 \text{ cm},$$

We are using 100W incandescent lamp among this only 90% of the electrical energy is converted into light, and 9-10% is lost as heat. Assume 6% of lamp's power is converted to visible light.
 $\therefore P_{source} = 6 \text{ W}$

$$\text{Then } E = \frac{6}{4\pi \times 3.14 \times (36.5 \times 10^{-2})^2} = 3.58 \text{ W/m}^2.$$

PROCEDURE

- 1 - place the solar cell and the light source opposite to each other on a wooden plank. Connect the circuit as shown in the figure through patch chords.
- 2 - Select the voltmeter range to 2V, current meter range to 2.5 mA and load resistance R_L to ∞ .
- 3 - switch on the lamp to expose the light on solar cell.
- 4 - set the distance between the solar cell and lamp in such a way that the current meter shows 2.5 mA deflections. Note down the observation of voltage and current.
- 5 - vary the load resistance using a resistance box and note down the current and voltage readings every time.
- 6 - plot a graph between output voltage vs output current by taking voltage along y-axis and current along x-axis.
- 7 - Determining fill factor and efficiency by drawing a rectangle having maximum area under the V-I curve and note the values of V_m and I_m . Note the voltmeter reading for open circuit V_{oc} and milliammeter reading with zero resistance, I_{sc} . Using these values, we can calculate the fill factor and efficiency for the cell.

$$\eta = \frac{1.12 \times 2 \times 10^{-3}}{3.58 \times 30 \times 10^{-4}} = \frac{0.00224}{0.0104} = \underline{\underline{0.208}}$$

maximum efficiency of practically used solar cells is about 0.2 (20%).

Error percentage in efficiency, $\epsilon = \frac{0.208 - 0.2}{0.2} \times 100$

$$= \underline{\underline{4\%}}$$

RESULT

V-I characteristics of solar cell plotted

solar cell Fill Factor, FF = 66.25%

Ideal value = 70% to 82%

Error percentage = 5.3%

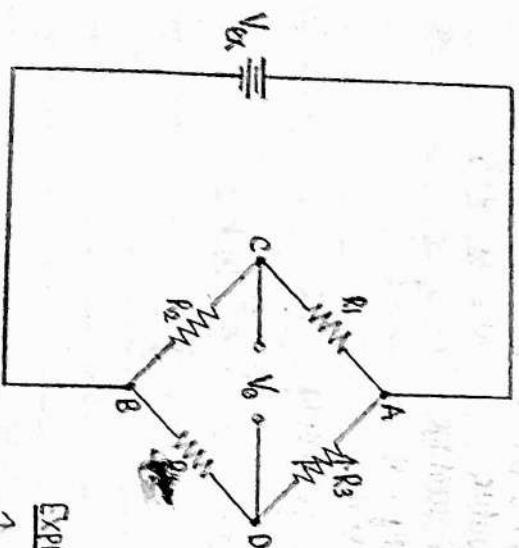
solar cell Efficiency, m = 20.8%

Ideal value = 20%

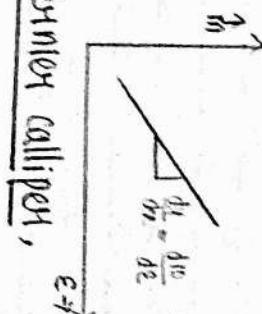
Error percentage = 4%

Chennai
15/11/04

A BASIC WHEATSTONE BRIDGE CONFIGURATION



EXPECTED GRAPH



The values measured using vernier calliper,
breadth of the cantilever, $b = 2.64 \text{ cm}$
The value measured using screw gauge
thickness of the cantilever, $t = 0.20 \text{ cm}$

A strain gauge is a device used to measure the amount of strain (deformation) in an object. It consists of a thin, electrically conductive foil pattern that is mounted on a backing material, which can be adhered to the surface of the object being measured. When the object deforms due to an applied force, the strain gauge deforms as well, causing a change in its electrical resistance. This change in resistance can be measured and is proportional to the strain experienced by the object.

The resistance of a conducting strain gauge wire can be expressed using the following equation:

$$R = \frac{R_L}{A} \quad \text{①}$$

EXPERIMENT 2

DATE - 31/12/2014

YOUNG'S MODULUS - STRAIN GAUGE

AIM

To determine the Young's modulus of a cantilever using strain gauge

APPARATUS REQUIRED

An aluminium cantilever fitted with strain gauge having slotless weight, a digital strain gauge voltage indicator.

THEORY

A strain gauge is a device used to measure the amount of strain (deformation) in an object. It consists of a thin, electrically conductive foil pattern that is mounted on a backing material, which can be adhered to the surface of the object being measured. When the object deforms due to an applied force, the strain gauge deforms as well, causing a change in its electrical resistance. This change in resistance can be measured and is proportional to the strain experienced by the object.

The resistance of a conducting strain gauge wire can be expressed using the following equation:

Observation and Calculations

$$At \Delta x = 9 \text{ cm} = 9 \times 10^{-2} \text{ m}^2 - \text{Gauge factor}$$

where,

R - is the resistance of the strain gauge wire
 ρ - is the electrical resistivity of the material of

the wire.

L - Length of the wire.
 A - is the cross-sectional area of the wire

The ratio of the relative change in electrical resistance to the mechanical strain experienced by the strain gauge is known as gauge factor GF. Mathematically it is expressed as:

$$GF = \frac{\Delta R}{R} / \epsilon \quad (2)$$

where,

ΔR - The change in resistance due to strain

R - Original resistance
 ϵ - Strain experienced by the strain gauge.

Weight (g)	Trial 1 $\times 10^3$ V	Trial 2 $\times 10^3$ V	Trial 3 $\times 10^3$ V	Average $V_0 (\times 10^3)$	$\epsilon = \frac{V_0 - V_0}{V_0} \times 10^6$	m/ϵ $(\times 10^6)$
50	0.09	0.09	0.09	0.09	19.46	2.57
100	0.18	0.18	0.18	0.18	38.91	2.57
150	0.27	0.27	0.27	0.27	58.37	2.57
200	0.36	0.36	0.36	0.36	77.83	2.57
250	0.45	0.45	0.45	0.45	97.29	2.57
300	0.54	0.54	0.54	0.54	116.75	2.57

Mean value of $m/\epsilon = 2.57 \times 10^6$ g

Young's modulus, $Y = \frac{3mgx}{A \epsilon L^2 \rho}$

for most metallic strain gauges, the gauge factor is typically around 2, but it can vary depending on the material and construction of the strain gauge.

Strain (ϵ) detected by the strain gauge can be calculated from the output voltage using gauge factor (GF):

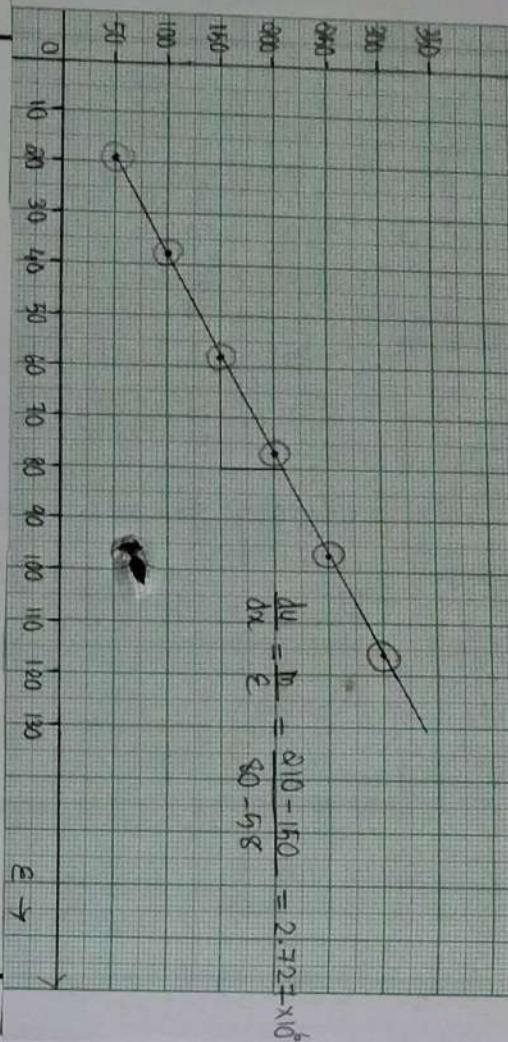
$$2.57 \times (0.20)^2$$

$$\begin{aligned} \text{Span of bridge} &= 6.367 \times 10^6 \text{ g/cm} \\ \text{Span of bridge} &= 6.367 \times 10^6 \text{ dynes/cm}^2 = 6.367 \times 10^6 \text{ N/m}^2 \end{aligned}$$

$$\epsilon = \frac{V_0}{GF \cdot V_0} \quad (3)$$

$x = 9 \text{ cm}$

Scale
x axis $1\text{cm} = 10 \times 10^{-6}$
y axis $1\text{cm} = 50.9$



From graph

$$\frac{m}{\epsilon} = 2.727 \times 10^6 \text{ g}$$

$$Y = \frac{3gx}{b^2} \times \frac{m}{\epsilon}$$

$$= \frac{3 \times 980 \times 9}{0.67(0.2)^2} \times 2.727 \times 10^6$$

$$= \underline{\underline{6.756 \times 10^9 \text{ dyne/cm}^2}} = \underline{\underline{6.756 \times 10^{10} \text{ N/m}^2}}$$

$$\text{Mean value of } Y = \underline{\underline{[6.367 \times 10^9] + [6.756 \times 10^9]}} = \underline{\underline{6.562 \times 10^{10} \text{ dyne/cm}^2}}$$

2

- where,
 V_0 - output voltage from the strain gauge.
 GF - gauge factor of the strain gauge
 V_{ex} - excitation voltage applied to the wheatstone bridge.

The strain gauge is used in conjunction with a wheatstone bridge to measure the small changes in electrical resistance that occur when the strain gauge is deformed due to mechanical stress. A wheatstone bridge is an electrical circuit used to measure unknown electrical resistances by balancing 4 legs of a bridge circuit. It consists of 4 resistances arranged in a diamond shape. The basic wheatstone bridge configuration is shown and it includes

- Two known resistances (R_1 and R_2)
- One variable resistor (R_3)
- one resistor representing the strain gauge (R_4)

The bridge is excited by an input voltage V_{ex} , and the output voltage V_0 is measured between the 2 midpoints of the bridge.

When strain is applied to the strain gauge, its resistance (R_4) changes. This causes the bridge to become unbalanced, resulting in a non-zero output voltage V_0 . The output voltage V_0 is proportional to the change in resistance of the strain gauge, which is proportional to the strain experienced by the gauge.

At $x = 10.2\text{cm}$

Weight (g)	Trial 1			Trial 2			Trial 3			Average $\varepsilon = \frac{\Delta L}{L_0}$	m/ε (g) $\times 10^6$
	$\frac{T}{10^3} \text{V}$										
0	0	0	0	0	0	0	0	0	0	0	-
50	0.11	0.11	0.11	0.11	0.11	0.11	23.48	23.48	23.48	2.102	-
100	0.21	0.21	0.21	0.21	0.21	0.21	45.40	45.40	45.40	2.20	-
150	0.30	0.30	0.30	0.30	0.30	0.30	64.86	64.86	64.86	2.31	-
200	0.40	0.40	0.40	0.40	0.40	0.40	86.48	86.48	86.48	2.31	-
250	0.50	0.50	0.50	0.50	0.50	0.50	108.108	108.108	108.108	2.31	-
300	0.60	0.60	0.60	0.60	0.60	0.60	129.72	129.72	129.72	2.31	-

$$\text{Mean } m/\varepsilon = 2.257 \times 10^6$$

Young's modulus $Y = \frac{3mgx}{bt^2\varepsilon}$

$$= \frac{3 \times 980 \times 10.2}{2.67 (0.20)^2} \times 2.257 \times 10^6$$

$$= 6.337 \times 10^1 \text{ dyne/cm}^2$$

Young's modulus $Y = 6.337 \times 10^1 \text{ dyne/cm}^2$

Young's modulus $Y = 6.337 \times 10^1 \text{ dyne/cm}^2$

Young's modulus $Y = 6.337 \times 10^1 \text{ dyne/cm}^2$

The relationship between the output voltage, gauge factor and strain is given by equation ③.

$$\varepsilon = \frac{V_0}{G.F.V.E} \quad ③$$

The young's modulus (Y) is a measure of the stiffness of a material. It is defined as the ratio of stress (σ) to strain (ε)

$$Y = \frac{\sigma}{\varepsilon} \quad ④$$

For a cantilever beam subjected to a load F at its free end, the stress is given by:

$$\sigma = \frac{6Fx}{bt^2} \quad ⑤$$

where,

F - Applied load (Force)

x - Distance between the point at which force acts and the centre of strain gauge

b - Breadth of the cantilever beam

t - Thickness of the cantilever beam.

By combining the equations for stress and strain from ③ and ⑤, young's modulus can be determined

$$Y = \frac{6F\alpha}{bt^2\varepsilon} = 6F\alpha G.F.V.E \quad ⑥$$

$$x = 10 \text{ cm}$$

scale
x-axis = 10 cm
Young's Mod = E

$$E = \frac{\sigma}{\epsilon} = \frac{10 - 150}{0.0 - 0.5} = 2.4 \times 10^6$$

ϵ

m

mm

mm

mm

mm

mm

mm

mm

mm

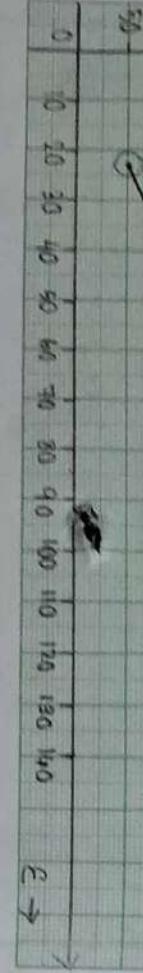
mm

from graph

$$\frac{M}{E} = 2.4 \times 10^6 \text{ g}$$

$$Y = \frac{39k}{bt^2} \times \frac{m}{E} = \frac{3 \times 980 \times 10^{-2}}{0.64 (0.20)^2} \times 2.4 \times 10^6 \\ = 6.738 \times 10^9 \text{ dynes/cm}^2$$

$$\text{mean value of } Y = \frac{[6.334 \times 10^9] + [6.738 \times 10^9]}{2} \\ = 6.538 \times 10^9 \text{ dynes/cm}^2$$



$$Y = \frac{3F^2}{b^2 E} = \frac{3mgx}{b^2 E} \quad (1)$$

where,
 F - Acceleration due to gravity
 m - mass of the load

PROCEDURE

- 1 - Set up the cantilever beam in the loading arrangement, fixing one end securely. The arrangement includes a strain voltage indicator which is adjusted to zero first.
- 2 - The breadth and thickness of the cantilever measured using vernier calliper and the distance between the point at which the load is applying and the centre of strain gauge is measured using a meter scale.
- 3 - The excitation voltage V_{ex} and gauge factor G_F given on the strain gauge is noted.

The value of young's modulus,

At $x = 9\text{cm}$,

$$Y = 6.562 \times 10^{11} \text{ dynes/cm}^2$$

At $x = 10.2\text{cm}$,

$$Y = 6.538 \times 10^{11} \text{ dynes/cm}^2$$

$$\text{mean } Y = \frac{[6.562 \times 10^{11}] + [6.538 \times 10^{11}]}{2}$$

$$= 6.55 \times 10^{11} \text{ dynes/cm}^2$$

The standard value of young's modulus of Aluminum cantilever is

$$Y = 690 \text{ Pa} = 6.9 \times 10^{11} \text{ dynes/cm}^2$$

$$\text{The error percentage} = \frac{[6.9 \times 10^{11}] - [6.55 \times 10^{11}]}{6.9 \times 10^{11}} \times 100$$

RESULT

The young's modulus of Aluminum cantilever,

$$\text{Modulus of elasticity} = \underline{\underline{5.0\%}}$$

$$Y = 6.55 \times 10^{11} \text{ dynes/cm}^2$$

$$\text{Error percentage} = \underline{\underline{5.0\%}}$$

4 - Gradually apply known weights at the free end of the beam to create a point load (F).

5 - For each applied load (F), record the corresponding output voltage from the strain gauge.

6 - Record the corresponding strain (ϵ) readings from the output voltage V_o , for each applied load, using gauge factor and excitation voltage by equation (3)

7 - Calculate the ratio between each applied load and Strain, that is m/e

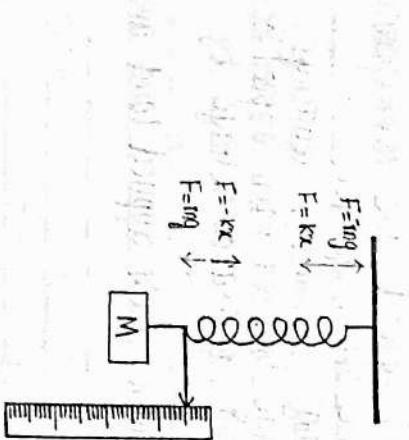
8 - Using equation (7),

$$Y = \frac{3mg}{bl^2\varepsilon}$$

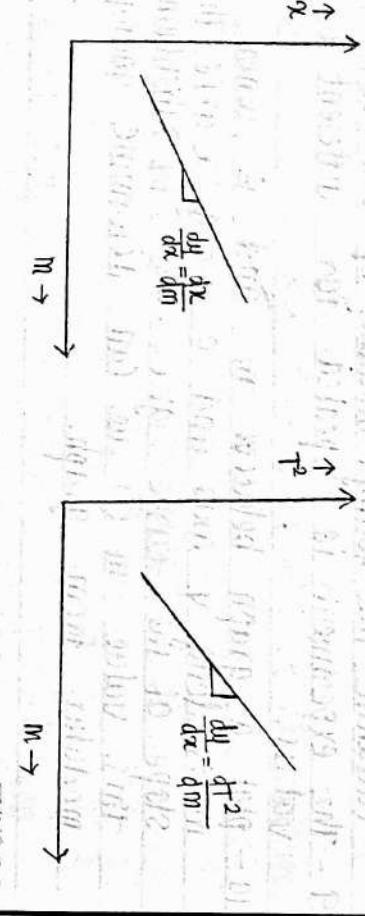
Calculate the young's modulus of cantilever
9 - The experiment is repeated for different x values.

10 - Plot a graph between m and ϵ , where m is along y axis and ϵ along x axis. The slope of the curve give m/e . By substituting this value in (7) we can determine young's modulus from graph.

DIAGRAM



EXPECTED GRAPHS



Mass of the spring = 44 g

$$\text{Effective mass } M_S = M_d = \frac{1}{3} \times 44 = \underline{\underline{14.6 \text{ g}}}$$

Actual length of the spring = 24 cm

EXPERIMENT 3

DATE - 6/2/2024

SPRING CONSTANT

- STATIC AND DYNAMIC METHOD

AIM

To determine the force constant of a spring by

- ① Static method.
- ② Dynamic method.

APPARATUS REQUIRED

Helical spring attached to a stand, slotted weights, metre scale and stop watch.

THEORY

A spring is an elastic object which stores mechanical energy. The spring constant k of an ideal spring is defined as the force per unit length and is different from one spring to another. Spring constant is represented in Newton/meter (N/m). It can be determined both in static as well as dynamic conditions. Two different techniques are used for determination of the spring constant. In the static method, Newton's law of motion is used for the equilibrium case, and laws of periodic motion are applied for determining the spring constant in

STATIC METHOD

OBSERVATION AND CALCULATION

METHOD

The dynamic case.

① Static method

Load $x10^3 \text{ kg}$	position of pointer $x10^3 \text{ m}$	Average $x10^2 \text{ m}$	shift for successive weight (x) $x = x_1 - x_0$ $x10^2 \text{ m}$	$F = mg$ (N)	$K_s = \frac{F}{x}$ (N/m)
0 + 14.6	23.7	23.6	23.65	0	
500 + 14.6	24.7	25.2	24.95	1.3	4.9
1000 + 14.6	27.2	27.2	27.2	3.55	9.8
1500 + 14.6	29.9	30.1	30	6.35	14.7
2000 + 14.6	32.8	33	32.9	9.25	19.6
2500 + 14.6	35.8	36	35.9	12.25	24.5
3000 + 14.6	38.7	38.7	38.7	15.05	29.4
					195.34

$$\text{Mean } K_s = \frac{276.06 + 281.49 + 211.89 + 200.00 + 195.34}{5}$$

5

$$F_{\text{up}} = -K_s x \quad \text{or} \quad F_{\text{up}} = K_s x \quad ①$$

From graph

$$\frac{dy}{dx} = \frac{dx}{dm} = \frac{(3.7 - 1.5)x10^{-2}}{(1.9 - 1.675)} = \frac{0.012}{0.225} = \underline{\underline{0.053}}$$

$$\frac{dm}{dx} = \frac{1}{0.053} = \underline{\underline{18.87}}$$

$$K_s = \frac{dm}{dx} x g = 18.87 \times 9.8 = \underline{\underline{185 \text{ N/m}}}$$

In this method of determination of spring constant, a weight is added to the spring and its extension is measured. The spring is fixed at one end and a weight is added in equal amounts one by one. After adding a weight the spring will attain a stationary position after some time. At equilibrium, there are two equal and opposite forces, acting upward and downward.

In equilibrium condition,
upward force = downward force

$$F_{\text{up}} = F_{\text{down}}$$

According to Hooke's law, the resulting force.

where, K_s is the spring constant. The negative sign indicates a restoring force, that is, the force that allows the object to return to its original shape and position.

$$F_{\text{down}} = mg \quad ②$$

Equating ① and ②, we get

(iii) Method 3

String Sling D.

Method 3 and 4

where,

m - Mass of the load applied.

g - Acceleration due to gravity.

k_s - Spring constant in the static condition.

x - Displacement of the spring from its equilibrium position.

Now, if we apply

Newton's 2nd law

of motion

of pulley

of string

However, the spring has a finite mass, denoted by M_s , which adds to the load, hence m in equation ④ is replaced by $(m+M_s)$, giving

$$k_s x = (m+M_s)g \quad \text{⑤}$$

② Dynamic method

If the spring is made to oscillate by pulling the weight applied to it downward, it executes a simple harmonic motion. The equation representing its motion is written as

$$\frac{d^2y}{dx^2} = \frac{k y}{m} \quad \text{⑥}$$

The angular velocity is given by,

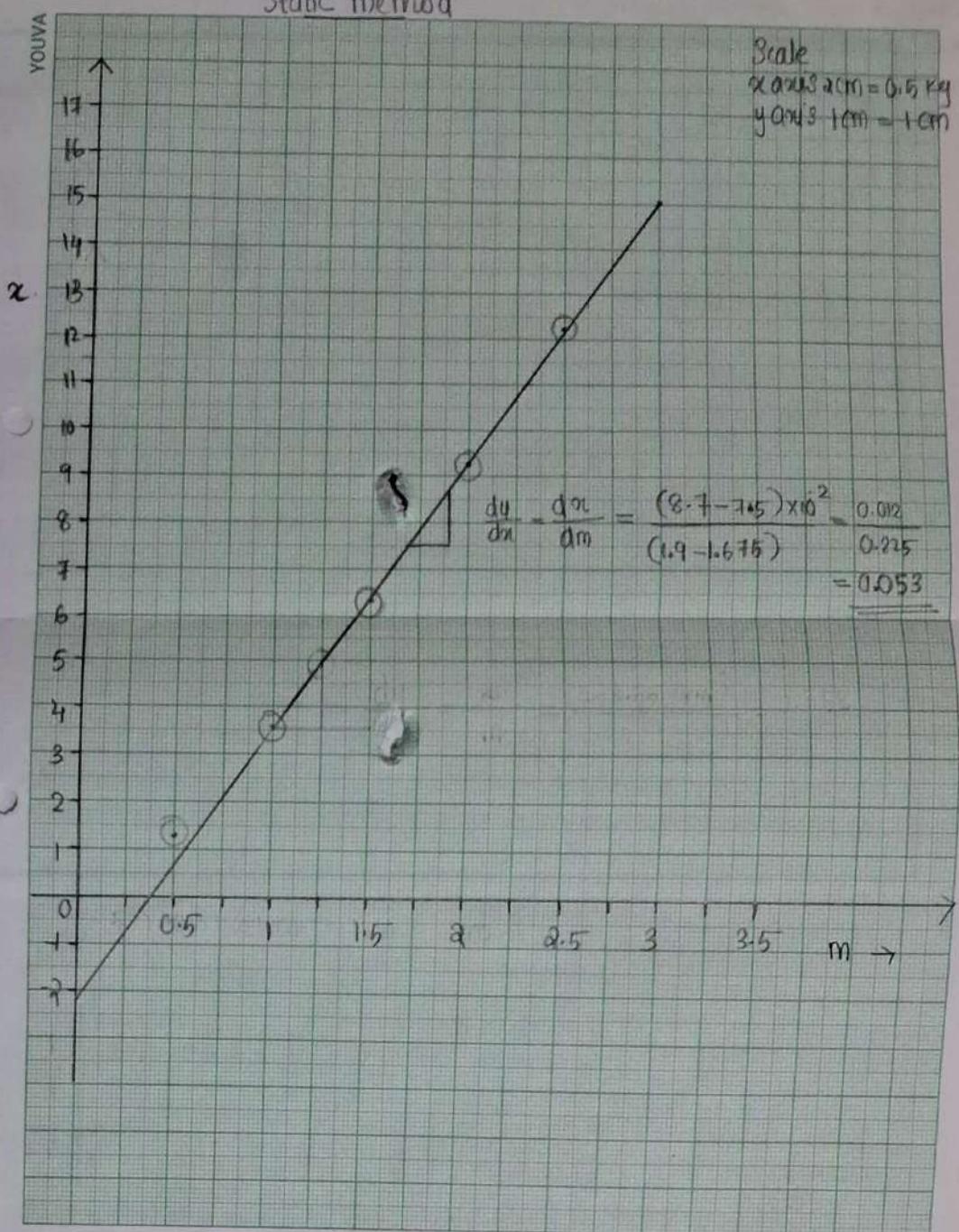
$$\omega = \sqrt{\frac{k}{m}} \quad \text{⑦}$$

$$\text{Error percentage} = \frac{188.95 - 185}{185} \times 100$$

$$= 1.7\%$$

Static method

Scale
 x axis 2 cm = 0.5 kg
 y axis 1 cm = 1 cm



as of the load applied.
 acceleration due to gravity
 spring constant in the static condition.
 displacement of the spring from its equilibrium position.

spring has a finite mass, denoted by
 is to the load, hence in equation
 by $(m+ms)$, giving

$$= (m+ms)g \quad \text{④}$$

method

is made to oscillate by pulling the
 ed to it downward, it executes a
 ntic motion. The equation representing
 s written as

$$\frac{d^2y}{dx^2} = \frac{ky}{m} \quad \text{⑤}$$

The angular velocity is given by,

$$\omega = \sqrt{\frac{k}{m}} \quad \text{⑥}$$

$$\begin{aligned} \text{Error percentage} &= \frac{222.95 - 185}{222.95} \times 100 \\ &= 17\% \end{aligned}$$

DYNAMIC METHOD

OBSERVATION AND CALCULATION

Load $m+M_d$ $\times 10^3 \text{ kg}$	Time for 10 oscillations		Average $T = t/10$ (s)	T^2 (s) ²	$K_d = 4\pi^2 (m+M_d)$ (T^2) N/m
	1 (s)	2 (s)			
500+14.6	6.61	6.97	6.79	0.3395	176.47
1000+14.6	8.84	9.26	9.05	0.4525	196.14
1500+14.6	11.75	11.72	11.74	0.3870	173.14
2000+14.6	13.88	13.23	13.55	0.6775	172.72
2500+14.6	15.29	15.25	15.27	0.4635	165.28
3000+14.6	15.82	16.27	16.05	0.645	184.32

Mean $K_d = 176.47 + 196.14 + 173.14 + 172.72 + 165.28 + 184.32$

6

$$= 178.01 \text{ N/m}$$

From graph

$$\frac{dy}{dx} = \frac{dT^2}{dm} = \frac{0.25 - 0.17}{1.996 - 0.7896} = 0.228$$

Effective mass in two methods can be eliminated by considering the shift corresponding to successive weight.

PROCEDURE

State method

- 1 - Attach a spring vertically to a stand and set measuring scale close to spring vertically.

$$K_d = 4\pi^2 \frac{dm}{dT^2} = 4\pi(3.14)^2 \times 4.385 = 172.93 \text{ N/m}$$

There fore, the time period of the oscillation of the spring is,

$$T = 2\pi = 2\pi \sqrt{\frac{m}{K}}$$

If the dynamic spring has an effective mass M_d , then its time period is,

$$T = 2\pi \sqrt{\frac{m+M_d}{K_d}}$$

$$K_d = 4\pi^2 \frac{(m+M_d)}{T^2} \quad (7)$$

where,

m - Mass of the weight hanging

M_d - Effective dynamic mass of the spring

T - Time period of oscillation

K_d - Spring constant in the dynamic condition.

Dynamic Method

2 - Measure the equilibrium position of the spring without any mass, x_0

3 - Hang the weight on the end of the spring one by one in equal amounts and measure new equilibrium positions, x_n

4 - Repeat the process of measuring equilibrium positions on unloading.

5 - Take average of the extension length on loading and unloading.

6 - Determine the displacement caused by the mass

7 - Using Hooke's Law, calculate the Spring constant in static condition (equation ④)

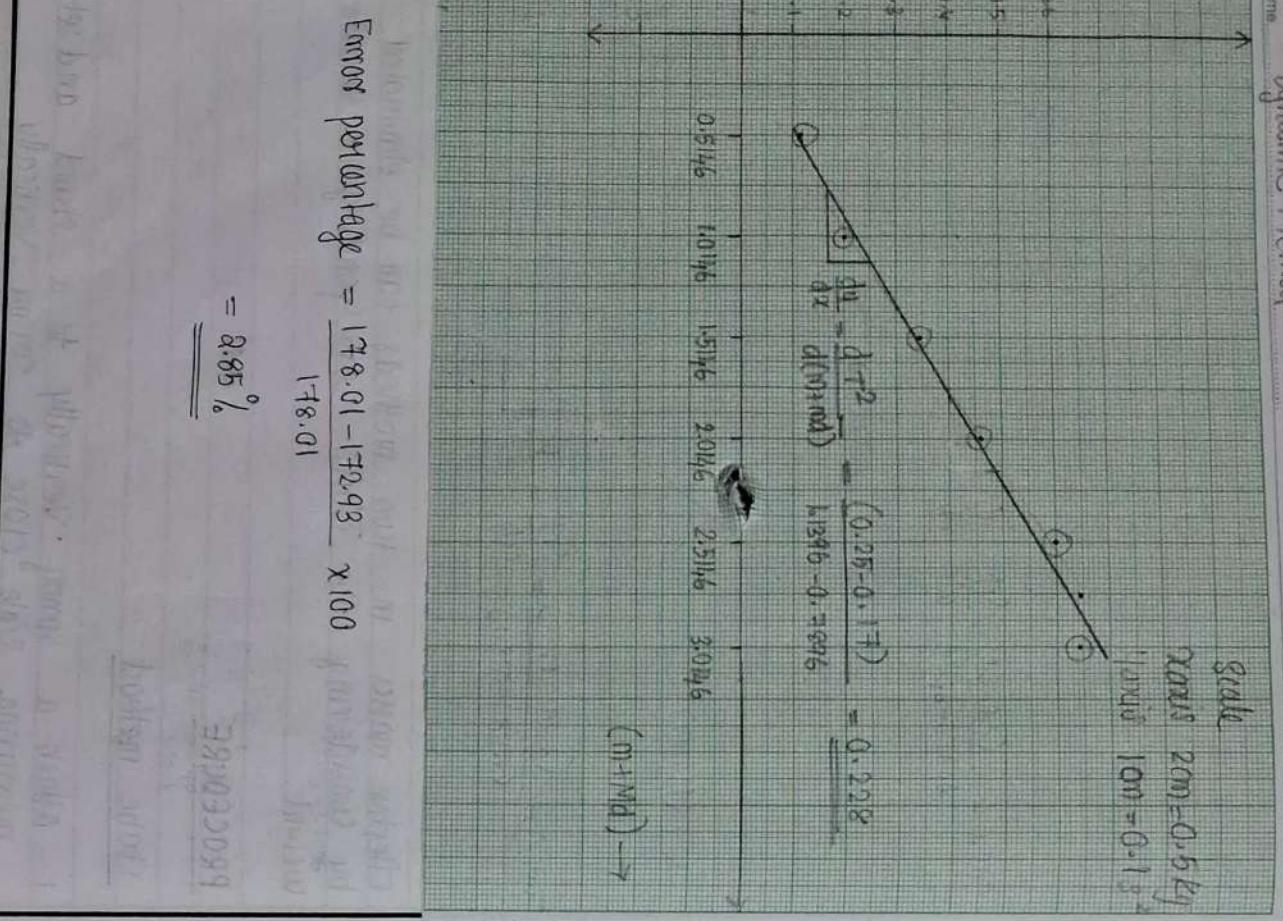
Dynamic method

1 - Attach a spring vertically to a stand

2 - Hang a weight 'm' from the spring
3 - Displace the mass slightly by pulling it from its equilibrium position and release it, allowing it to oscillate.

4 - Use a stopwatch to measure the time for 20 oscillations

5 - Repeat the process two times and calculate the average period (T) by dividing the total time by the number of oscillations.
6 - Using the simple harmonic motion equation ⑦, calculate the dynamic spring constant for the spring.



RESULT

By static method

Spring constant from calculation , $k_d = 2220.95 \text{ N/m}$
Spring constant from graph , $k_d = 185 \text{ N/m}$
Error percentage = 17%

By dynamic method

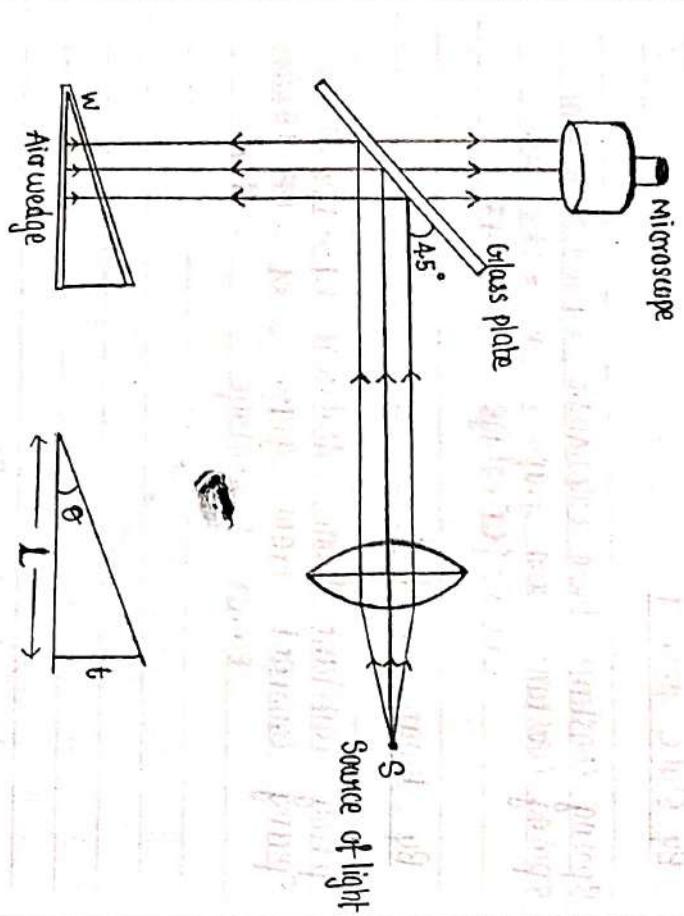
Spring constant from calculation , $k_d = 178.01 \text{ N/m}$
Spring constant from graph , $k_d = 172.93 \text{ N/m}$
Error percentage = 2.85%

Data Sheet

~~1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00~~



DIAGRAM



EXPERIMENT 4

DATE - 6/2/2024

COMPARISON OF THICKNESS OF THIN SHEETS BY AIR WEDGE

SHEETS BY AIR WEDGE

AIM

To determine the thickness of different thin sheets and compare with each other.

APPARATUS REQUIRED

Air wedge, Travelling microscope, sodium vapour lamp, Reading lens, thin sheets, plane glass plate.

THEORY

When a piece of thin paper is introduced between two parallel transparent polished glass plates, a wedge of air is trapped between the two glass plates. When monochromatic light is incident on this arrangement, it undergoes multiple reflections between the two glass plates leading to an interference pattern of alternating bright and dark fringes.

Constructive interference occurs when the path difference between the two reflected waves is an integer multiple of the wavelength ($n\lambda$). This results in bright fringes. Destructive interference occurs when the path difference is an odd multiple of half wavelength.

Least count of travelling microscope LC = 0.001 cm

wavelength of monochromatic light (sodium lamp) = 589×10^{-9} m

OBSERVATIONS AND CALCULATION

To determine the thickness of sheet 1 METHODS

$$L = 5.8 \times 10^2 \text{ m}$$

$$LC = 0.001 \text{ cm}$$

SETTING

$$\Delta = 2t$$

$$(n+1) \frac{\lambda}{d} . \text{ This results in dark fringes.}$$

The path difference between the two reflected rays is given by

$$\textcircled{1}$$

Order	Microscope reading cm	Total reading cm	width of 10 bands cm
	MSR cm	VSR cm	MSR + (VSR × LC)
2	7.05	9	7.059
4	7.05	13	7.063
6	7.10	40	7.140
8	7.15	25	7.175
10	7.20	0	7.200
12	7.20	3.2	7.232
14	7.25	1	7.251
16	7.25	12	7.262
18	7.30	29	7.329
20	7.35	2	7.352

Mean width of 10 bands = $0.1578 \times 10^{-2} \text{ m}$

$$\text{bandwidth } \beta = \text{Total width of 10 bands} = 0.1578 \times 10^{-2} = 0.1578 \times 10^3$$

$$\tan \theta = \frac{t}{L} \quad \textcircled{4}$$

$$t = L \tan \theta$$

The thickness of the air wedge at a distance 'x' from the edge is,

$$t = x \tan \theta \quad \textcircled{5}$$

For constructive interference at point 'x',

$$2t = n\lambda$$

Order	Microscope reading cm	Total reading cm	width of 10 bands cm
2	7.05	9	7.059
4	7.05	13	7.063
6	7.10	40	7.140
8	7.15	25	7.175
10	7.20	0	7.200
12	7.20	3.2	7.232
14	7.25	1	7.251
16	7.25	12	7.262
18	7.30	29	7.329
20	7.35	2	7.352

$$\beta = 0.1578 \times 10^3 \text{ m}$$

$$\lambda = 589 \times 10^{-9} \text{ m}$$

$$L = 5.8 \times 10^2 \text{ m}$$

$$\text{Thickness of sheet 1, } t_1 = \frac{\Delta L}{\beta} = \frac{589 \times 10^{-9} \times 5.8 \times 10^2}{0.1578 \times 10^3} \text{ m} = 1.0824 \times 10^{-4} \text{ m}$$

(Method 2)
Method 2 uses the principle of thin film interference to determine the thickness of the sheet.

To determine the thickness of sheet 2

$$L = 6.2 \times 10^{-2} \text{ m} \quad Lc = 0.001 \text{ cm}$$

$$\therefore 2 \alpha \tan \theta = n \lambda \quad (6)$$

For n corresponding to the n th fringe,

$$2 \lambda n \tan \theta = n \lambda$$

Order	Microscope reading MSR cm	VSR cm	Total reading MSR + (VSR x 10) cm	Width of 10 bands cm
2	6.95	0	6.950	
4	7.00	45	7.045	
6	7.00	10	7.010	
8	7.05	17	7.067	
10	7.10	43	7.143	
12	7.10	40	7.140	0.190
14	7.15	24	7.174	0.130
16	7.20	18	7.218	0.108
18	7.20	10	7.210	0.143
20	7.25	30	7.280	0.137

Mean width of 10 bands = $0.1616 \times 10^{-2} \text{ m}$

Band width, $\beta = \frac{\text{Total width of 10 bands}}{10} = \frac{0.1616 \times 10^{-2}}{10} = 0.1616 \times 10^{-3} \text{ m}$

$$\beta = 0.1616 \times 10^{-3} \text{ m}$$

$$\lambda = 589 \times 10^{-9} \text{ m}$$

$$L = 6.2 \times 10^{-2} \text{ m}$$

$$\text{Thickness of sheet 2, } t_2 = \frac{\beta L}{\delta \beta} = \frac{589 \times 10^{-9} \times 6.2 \times 10^{-2}}{2 \times 0.1616 \times 10^{-3}}$$

$$= 1.13 \times 10^{-4} \text{ m}$$

	$\beta = \frac{n \lambda L}{\delta t}$
Then equation (7) becomes,	$2 \lambda n \tan \theta = n \lambda$
And using the geometry of the wedge,	$2 \lambda n \tan \theta \approx n \lambda$
when the angle θ is very very small, then	$2 \lambda n \tan \theta \approx 2 \lambda n \theta$
tan $\theta \approx \theta$.	$2 \lambda n \theta = n \lambda$
$\theta \approx \frac{\delta t}{L}$	$2 \lambda n \frac{\delta t}{L} = n \lambda$
$\therefore 2 \lambda n \frac{\delta t}{L} = n \lambda$	$\frac{\delta t}{L} = \frac{\lambda}{2 \lambda n}$
$\therefore \frac{\delta t}{L} = \frac{1}{2 n}$	$\frac{\delta t}{L} = \frac{1}{2} \frac{1}{n}$
$\therefore \frac{\delta t}{L} = \frac{1}{2} \frac{\lambda}{\lambda}$	$\frac{\delta t}{L} = \frac{1}{2}$
The fringe width or band width ' β ' in the interference pattern is the distance between two consecutive bright or dark fringes.	
$\beta = \lambda n + 1 - \lambda n$	
$= (n+1) \lambda - n \lambda$	
$\frac{\delta t}{L} = \frac{\lambda}{2}$	
$\frac{\delta t}{L} = \frac{1}{2}$	

APPARATUS

$$\therefore \text{The thickness, } t = \frac{\lambda L}{\Delta \beta}$$

where,

λ — wavelength of the light used

L — length of the air wedge, the distance over which the plates are separated

$\Delta \beta$ — fringe width

t — thickness of the air wedge

PROCEDURE

- 1 — place a thin sheet, whose thickness is to be measured between two glass plates to form an air wedge. The thin sheet is placed at one end or near to the end. The other end of the plates is held tight by a rubber band so that it becomes the line of contact. Measure the length (l) of air wedge.
- 2 — Switch on the sodium vapour lamp.
- 3 — A wooden box provided with glass plate inclined at 45° and the monochromatic light from the Sodium Vapour lamp is allowed to fall on this glass plate.
- 4 — place the air wedge inside the wooden box such that the reflected light from the glass plate is incident normally on the air wedge.
- 5 — Adjust the travelling microscope which is placed vertically above the inclined glass plate and already to view interference band clearly. Focus the cross wires exactly.
- 6 — Measure the distance corresponding to 20 bright or dark fringes using the travelling microscope.

7 - width of 10 fringes deduced and the fringe width

(β) is calculated by dividing the measured distance on the number of fringes. The measurements are recorded in a suitable table

$$t = \frac{\lambda L}{\beta} \quad \text{or} \quad t = \frac{\lambda L}{\alpha \beta}$$

the thickness of wedge is determined.

RESULTS

width of 10 fringes = 0.095 ± 0.005

length of wedge = $1.082 \times 10^{-4} \text{ m}$

value of λ = 5890 Å

value of α = $1.13 \times 10^{-4} \text{ m}^{-1}$

value of β = $1.082 \times 10^{-4} \text{ m}^{-1}$

value of t_1 = $1.082 \times 10^{-4} \text{ m}$

value of t_2 = $1.13 \times 10^{-4} \text{ m}$

value of t_3 = $1.082 \times 10^{-4} \text{ m}$

value of t_4 = $1.082 \times 10^{-4} \text{ m}$

value of t_5 = $1.082 \times 10^{-4} \text{ m}$

value of t_6 = $1.082 \times 10^{-4} \text{ m}$

value of t_7 = $1.082 \times 10^{-4} \text{ m}$

value of t_8 = $1.082 \times 10^{-4} \text{ m}$

value of t_9 = $1.082 \times 10^{-4} \text{ m}$

value of t_{10} = $1.082 \times 10^{-4} \text{ m}$

RESULT

The thickness of sheet 1, $t_1 = 1.082 \times 10^{-4} \text{ m}$

The thickness of sheet 2, $t_2 = 1.13 \times 10^{-4} \text{ m}$

\checkmark

EXPERIMENT 5

DATE - 8/1/2024

MALUS LAW - VERIFICATION

AIM

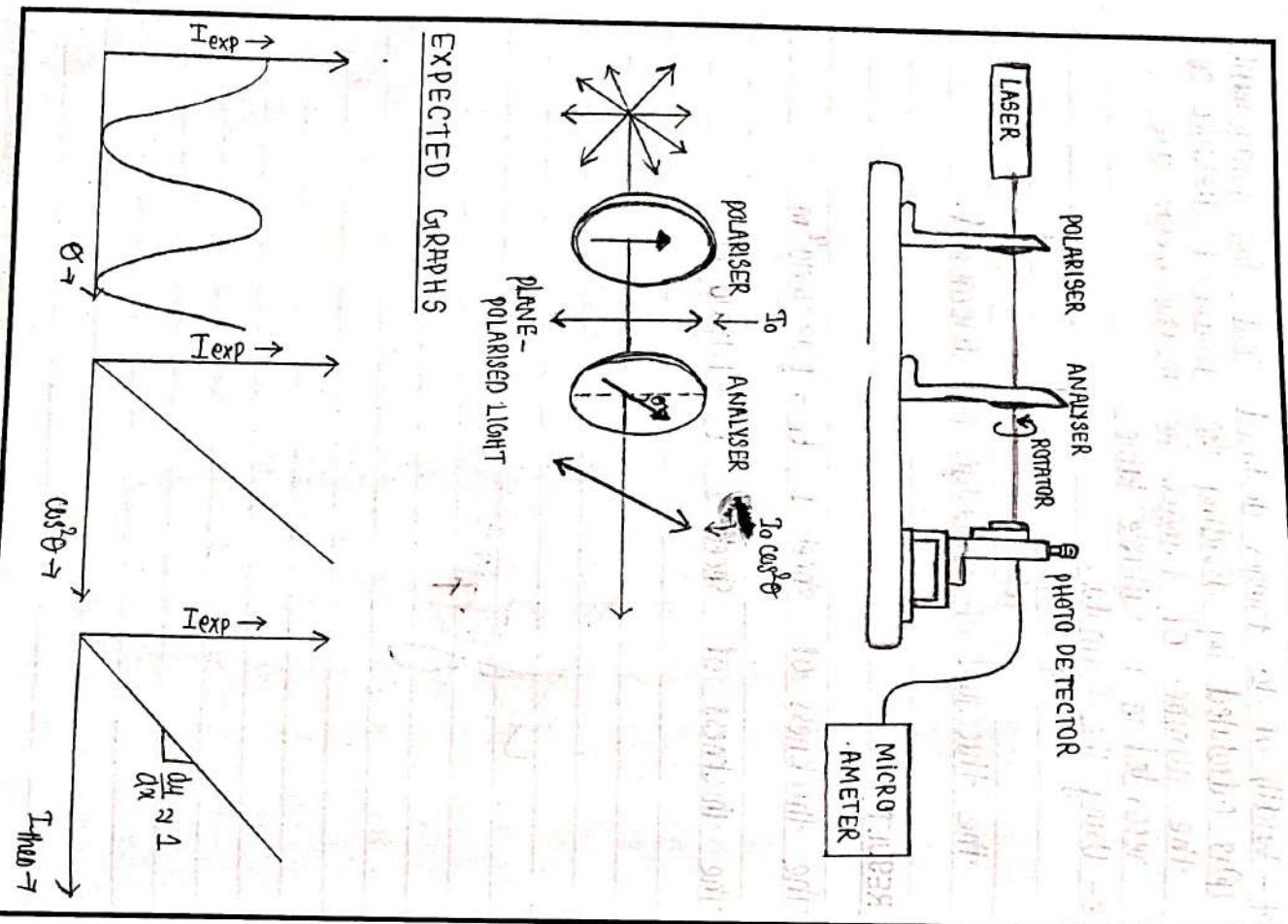
To determine the relationship between the intensity of the transmitted light through analyzer and ' θ ', the angle between the axes of polarizer and analyzer and to verify Malus law.

APPARATUS REQUIRED

A diode laser, a polarizer, analyzer pair, photo detector, detector output measuring unit (CUA) and an optical bench.

THEORY

The light coming from the sun, candle light, and light emitted by a bulb is an ordinary light and is known to be un-polarized. In an un-polarized light electric and magnetic field vectors vibrate in all possible directions perpendicular to each other and also perpendicular to the direction of propagation of light. When an unpolarized light falls on a polarizer, the transmitted light gets polarized. The polarized light falling on another polaroid called analyzer, transmits light depending on the orientation of its axis with the polarizer.



OBSERVATION AND CALCULATION

Angle of analyzer when current is maximum, $\phi_0 = 60^\circ$

Maximum current, $I_{\text{max}} = 1 \text{ mA}$

Angle of analyzer [degrees]	Angle between the axes of polarizer and analyzer $\theta = \phi - \phi_0$ [degrees]	cos θ	$\omega \sin^2 \theta$	Current I_t = Intensity = $I_{\text{max}} \times \omega \sin^2 \theta$ (mA)
0	-60	0.5	0.1	0.25
10	-50	0.64	0.41	0.32
20	-40	0.77	0.60	0.40
30	-30	0.87	0.76	0.50
40	-20	0.94	0.88	0.60
50	-10	0.98	0.96	0.70
60	0	1	1	0.80
70	10	0.96	0.9	0.96
80	20	0.94	0.88	0.88
90	30	0.87	0.76	0.76
100	40	0.77	0.60	0.60
110	50	0.64	0.41	0.41
120	60	0.5	0.25	0.25
130	70	0.34	0.12	0.12
140	80	0.14	0.03	0.03
150	90	0	0	0
160	100	-0.14	0.03	0.03
170	110	-0.34	0.12	0.12

Malus's law states that when a completely plane polarized light is incident on the analyzer, the intensity (I_t) of the light transmitted by the analyzer is directly proportional to the square of the cosine of angle between the transmission axes of the analyzer and the polarizer.

$$I_t \propto \cos^2 \theta$$

If A_0 is the amplitude of the incident light and A_t is amplitude of the light transmitted through the analyzer, which is inclined at an angle θ with the polarizer then,

$$A_t = A_0 \cos \theta$$

As, intensity $\propto (\text{amplitude})^2$

$$I_t = A_t^2 = A_0^2 \cos^2 \theta = I_0 \cos^2 \theta$$

where,
 I_t - Intensity of light transmitted through analyzer.

I_0 - Intensity of incident plane polarized light.
 θ - Angle between axis of polarizer and analyzer.

$$\text{Thus} = I_{\text{max}} \cos^2 \theta$$

PROCEDURE

- 1 - set up the laser, photodiode, the polarizer and analyzer as shown in figure. Align the polarizer and analyzer so that their transmission axes are parallel.
 - 2 - keep the polarizer fixed and rotate the analyzer until you observe a maximum in transmission. Note down maximum current I_{max} and angle ϕ . If it is difficult to find the maximum intensity, plot a graph between I_{exp} and ϕ , which is the angle of analyzer and obtain the angle corresponding to maximum current.
 - 3 - Rotate the analyzer in 10° increments
 - 4 - For each angle ϕ , measure the transmitted light intensity I_{exp} using the photo detector.
 - 5 - By subtracting I_{max} , the angle corresponding to maximum intensity from ϕ , θ can be find, which is the angle between the axes of polarizer and analyzer.
 - 6 - The general value of intensity can be find using the expression
- $$I_{theo} = I_{max} \cos^2 \theta$$
- # - Verifying malus law by plotting graph between
 - ① T_{exp} vs θ , T_{exp} in y axis and θ in x axis
 - ② T_{exp} vs $\cos^2 \theta$, T_{exp} in y axis and $\cos^2 \theta$ in x axis
 - ③ T_{exp} vs I_{theo} , T_{exp} in y axis and I_{theo} in x axis

Malus law

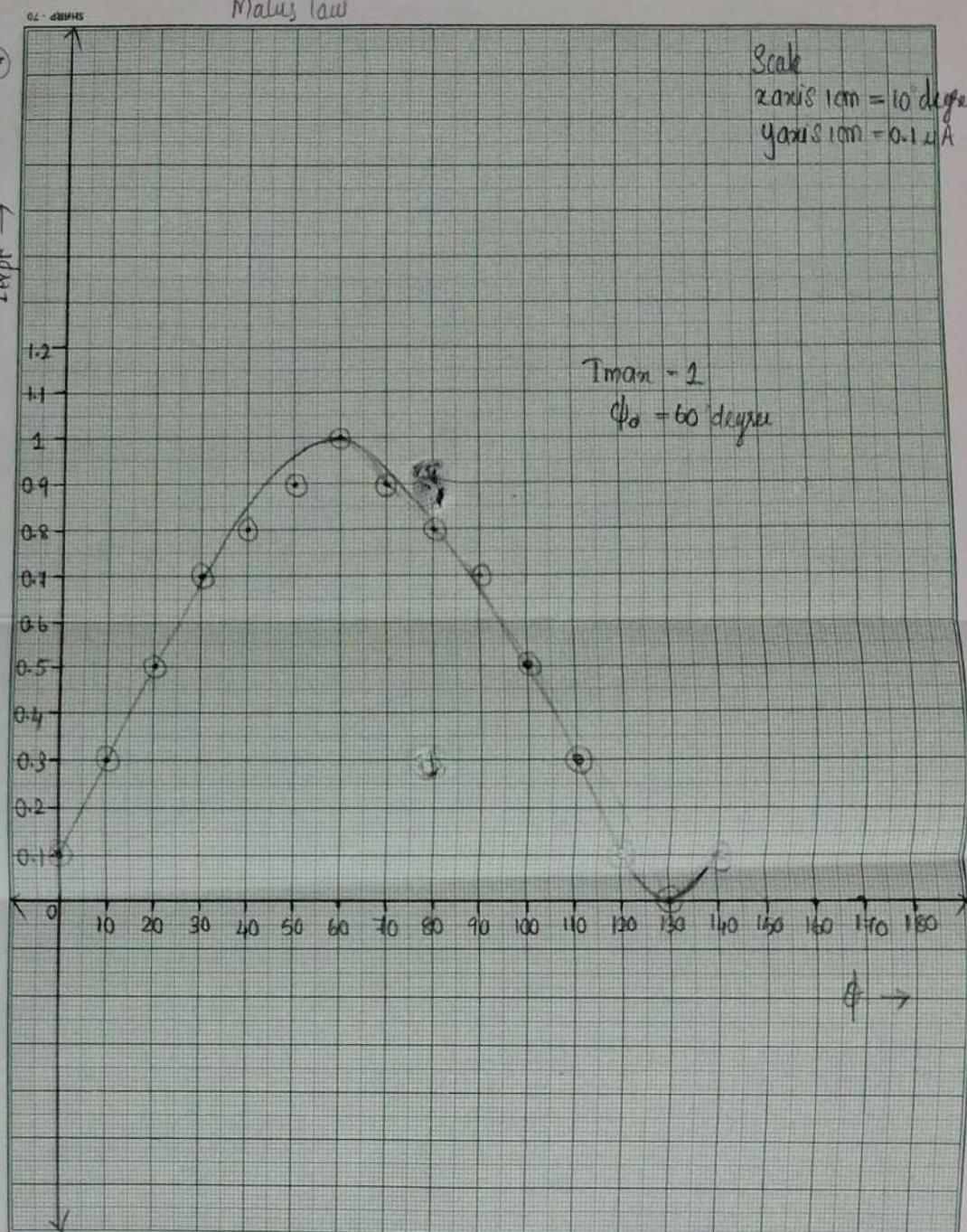
Scale

x axis 1cm = 10 degree

y axis 1cm = 0.1 uA

$$T_{\max} = 1$$

$$\phi_0 = 60 \text{ degrees}$$



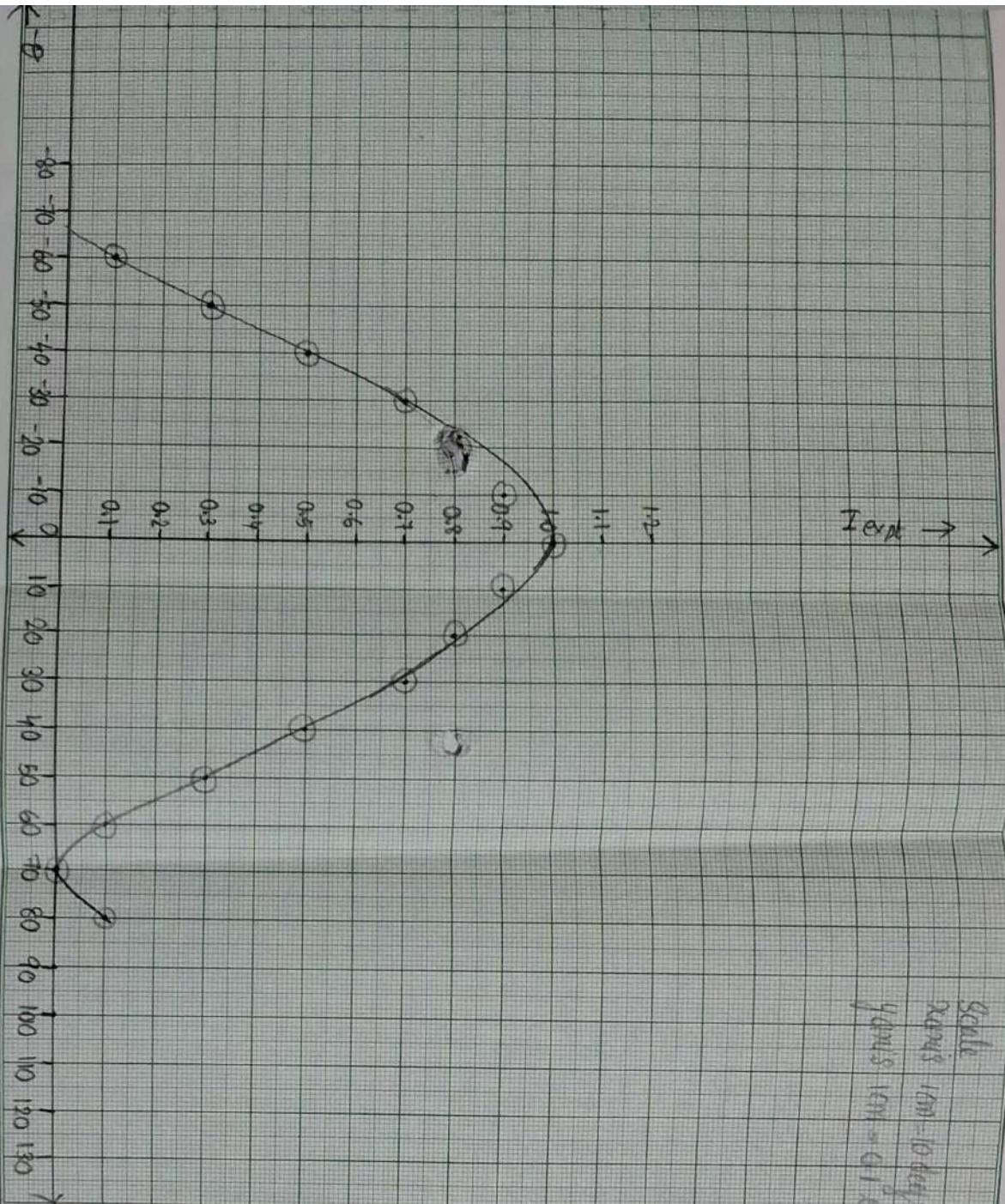
1. photodiode, the polarizer and analyzer
gure. Align the polarizer and analyzer
so transmission axes are parallel.
Set fixed and rotate the analyzer
to have a maximum in transmission.
maximum current I_{\max} and angle at
which it occurs. It is difficult to find the maximum
current. It is difficult to find the maximum current.
To a graph between T_{\max} and ϕ ,
angle of analyzer and obtain
corresponding to maximum current.
Analyze in 10° increments
at each ϕ , measure the transmitted
intensity using the photo detector.
At each ϕ , the angle corresponding to
maximum intensity from ϕ , θ can be
calculated by using the formula
 $\theta = \tan^{-1}(\tan \phi / \sqrt{1 - T_{\max}})$
The angle between the axes
 ϕ and θ can be found using
 $\phi - \theta = \tan^{-1}(I/I_{\max})$

$$I = I_{\max} \cos^2 \theta$$

1. Plot graph between I/I_{\max} and ϕ .
2. Plot graph between I/I_{\max} and θ .
3. Plot graph between θ and ϕ .

Scale
Range 160-10 degree
from 10-0 to 10-10 A
T_{exp} ↑

SHARP - 70



- 1, photodiode, the polarizer and analyzer are fixed and rotate the analyzer to observe a maximum in transmission.
- maximum current I_{max} and angle as difficult to find the maximum to a graph between T_{exp} and ϕ , angle of analyzer and obtain corresponding to maximum current.
- analyzer in 10° increments i.e. ϕ , measure the transmitted T_{exp} using the photo detector.
- so, the angle corresponding to intensity from ϕ , θ can be
- is the angle between the axes H and analyzer.
- use of intensity can be find using
- $I = I_{max} \cos^2 \theta$
- using law by plotting graph between θ , T_{exp} in y axis and θ in x axis
- (2) T_{exp} vs $\cos^2 \theta$, T_{exp} in y axis and $\cos^2 \theta$ in x axis
- (3) T_{exp} vs I_{thru} , T_{exp} in y axis and I_{thru} in x axis

RESULT

Malus law verified from the experimental data.

The slope of straight line in graph $\tan \theta$ vs $\sin^2 \theta$ is calculated.

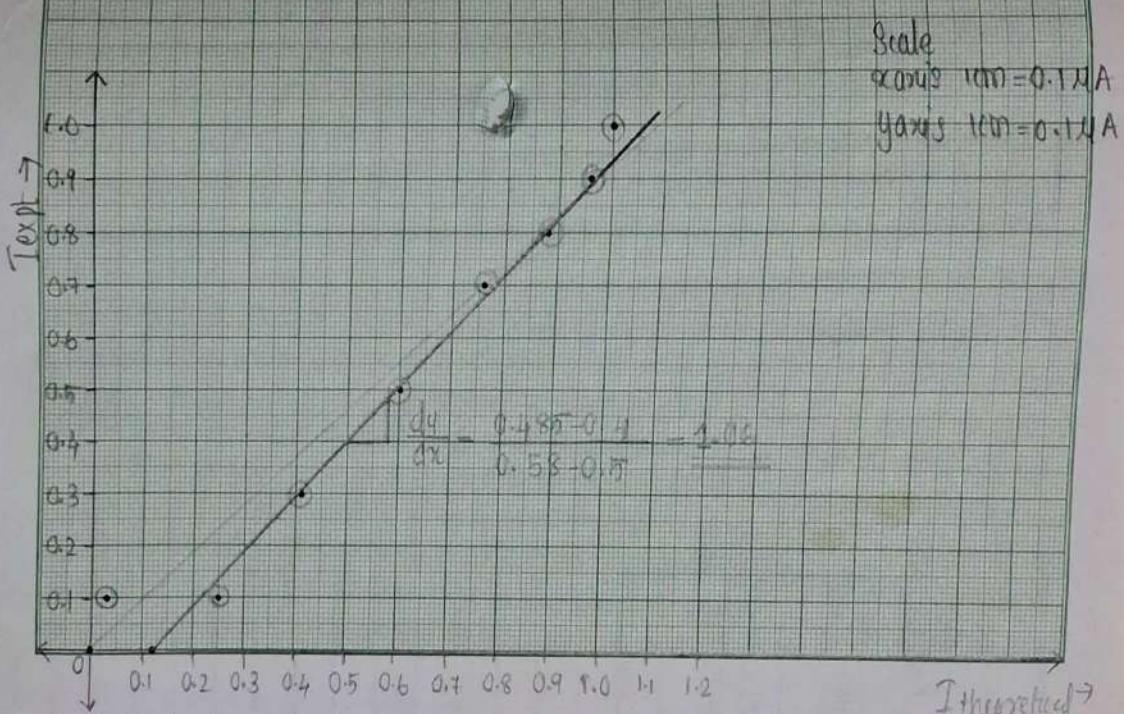
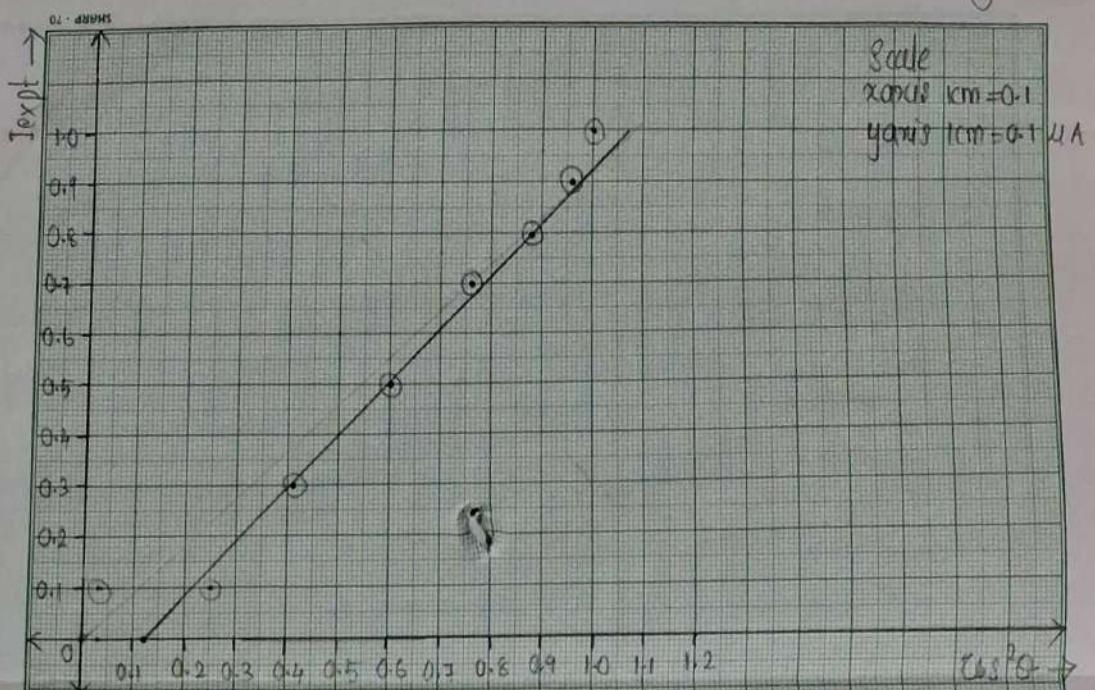
$$\text{slope} = 1.06 \approx 1$$

unit slope indicating the correctness of Malus's law.

Temp vs θ , Temp vs $\cos^2 \theta$ has been plotted.

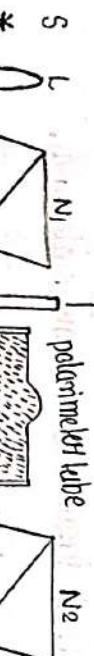
~~Malus's Law~~

①



I theoretical

- from the experimental data.
- If line in graph Expt vs Theor is
2. $\frac{1}{\cos^2 \theta}$
- The correctness of Malu's law.
- $\frac{1}{\cos^2 \theta}$ has been plotted.



N₂

E

Analyzer
Eye piece.

Light
source

* N₁

polarizer

H

Half shade on
Biquartz deinde

polarimeter tube

N₂

N₃

polarizer

S

TUTORIAL

SPECIFIC ROTATION MEASUREMENT

AIM

Using half shade polarimeter, rotation (α) versus concentration (C) curve to be drawn and to find specific rotation of sugar solution and compare with the standard value.

APPARATUS REQUIRED

source of light (sodium lamp for half-shade polarimeter), glass beaker, water, sugar, digital balance

THEORY

A polarimeter consists of two Nicols termed as polarizer and analyzer. These can be rotated about a common axis and the substance for which the rotation is to be determined, is placed in a tube in between these two. The half shade plate is placed between the polarizer and the solution tube.

The polarizer is a circular plate with two halves. One half is made of quartz cut parallel to its optic axis, and is thick enough to create a half-wavelength delay for sodium light. The other half is made of glass, matched in thickness so that

OBSERVATION AND CALCULATIONS

$$\text{Leaf bent} = \frac{1}{10}^\circ = 0.1^\circ$$

$$L = 0.1 \times 20 = 2 \text{ dm}$$

ROTATION MEASUREMENT

Concentration g/ml (C)	Polarimeter reading in degree MSR	Polarimeter reading in degree VSR	MSR + (VSR × C)	Angle of rotation in degree (θ)	Specific rotation $\alpha = \frac{\theta}{LC}$ $(\text{g/ml})^{-1} (\text{dm})^{-1}$
0	188	5	188.5	0	
0.05	195	8	195.8	+3	73
0.1	200	4	200.1	11.6	58
0.15	206	7	206.7	18.2	-55.8
0.2	215	2	215.2	26.7	66.75

Mean specific rotation = $68.38^\circ (\text{g/ml})^{-1} (\text{dm})^{-1}$

Standard value of specific rotation at sucrose = $66.5^\circ (\text{g/ml})^{-1} (\text{dm})^{-1}$

Error percentage

$$= \frac{66.5 - 68.38}{66.5} \times 100$$

$$= \underline{\underline{2.82\%}}$$

The light passing through it has the same intensity as the light from the quartz. As a result, a plane polarized light beams emerge, one from glass half and one from the quartz half. When these two equal-intensity beams are aligned with the main section of an analyzer, both halves of the field of view seen through the eyepiece will appear equally bright.

When we place a tube of sugar solution between the polarizer and analyzer, it rotates the plane of polarized light. We measure this rotation to understand the optical activity of the sugar solution, which is described by its specific rotation ' α '.

Specific rotation is a measure of how much a substance can rotate the plane of polarized light.

It tells us how much the light's direction changes when it passes through a certain amount of the substance in a solution. If the light turns to the right, the substance has a positive specific rotation; if it turns to the left, it has a negative specific rotation.

The specific rotation can be estimated as,

$$\alpha = \frac{\theta}{LC} = \theta V$$

where, θ - Angle of rotation in degree
 L - Path length of the solution (length of the tube in decimeters)

C - Concentration of the solution in g/ml

$$C = \frac{m}{V}$$

Rotating Power

Optical Rotatory Power

Optical Density

Optical Rotatory Power

where, m — Mass of the sample in gram
 V — Volume of the solution in milliliter.

specific rotation α can be defined as the angle of rotation (θ) caused by an optically active substance when polarized light passes through a solution of the substance at a specific concentration and path length.

PROCEDURE

- 1— switch on the power of the polarimeter instrument.
- 2— illuminate the sodium lamp at maximum emission.

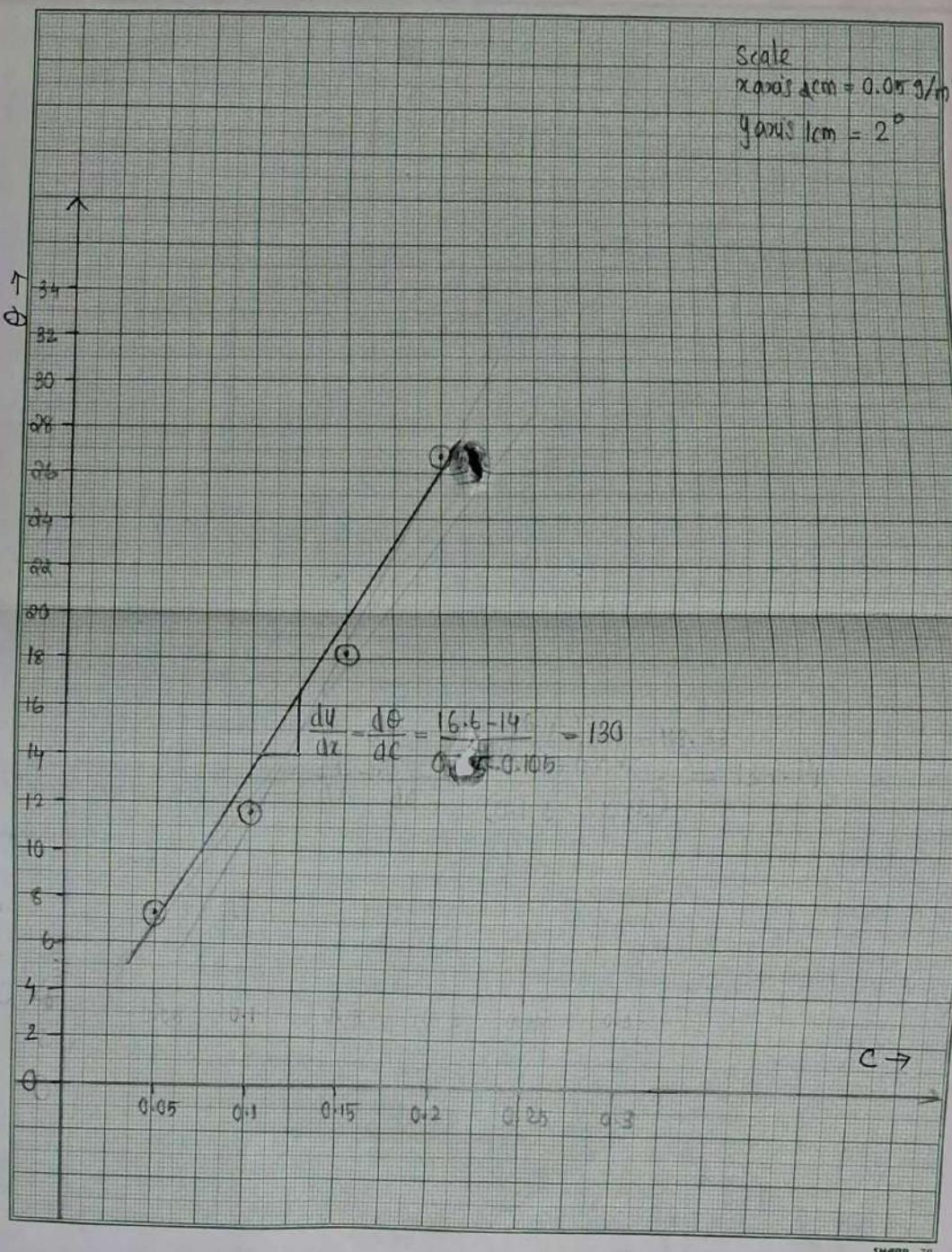
The light will pass through the solution tube.
 3— Fill the sample tube with distilled water, and place the tube in the polarimeter and set the instrument to zero. This step ensures that any rotation observed later is only due to the sugar solution.

4— Prepare a sugar solution of known concentration by dissolving a known mass of sugar in a known volume of distilled water. In this, we are dissolving 5 grams of sugar in 100 milliliters of water

To make a 5% solution
 5— Carefully fill the sample tube with the prepared sugar solution. Ensure there are no air bubbles, as these can affect the accuracy of the measurement.

6— Place the sample tube in the polarimeter.
 7— Observe and record the angle of rotation ' θ '.

Scale
x-axis $\text{cm} = 0.05 \text{ g/ml}$
y-axis $\text{cm} = 2^\circ$



SHARP - 70

of the solute in gram
2. Of the solution in milliliter.

can be defined as the angle caused by an optically active polarized light passes through a substance at a specific concentration

of the polarimeter instrument.
Sodium lamp at maximum emission.
Pass through the solution tube.

Tube with distilled water, and place in polarimeter and set the instru-
ment. This step ensures that any rotation
is only due to the sugar solution,
or solution of known concentration.
A known mass of sugar in a known
volume of water. In this, we are dissolving
sugar in 100 milliliters of water
5% solution

the sample tube with the prepared

as these can affect the accuracy of the
measurement.

- 6 - place the sample tube in the polarimeter.
- 7 - observe and record the angle of rotation ' θ '

symbol of sugar - It is used to reduce
salt hardness reducing the salt content -
thus reducing its density.
Thus we reduce air to polarization.

From graph

$$\frac{dy}{dx} = \frac{d\theta}{dc} = \frac{16.6 - 14}{0.125 - 0.105} = 130$$

Specific rotation $\alpha = \frac{\theta}{Lc}$

$$= \frac{1}{L} \frac{d\theta}{dc}$$
$$= \frac{1}{2} \times 130 = 65^{\circ}(\text{gluc})^1(\text{dm})^{-1}$$

Error percentage = $\frac{66.5 - 65}{66.5} \times 100$

$$= 2.25\%$$

This is the angle by which the plane of polarized light is rotated after passing through the sugar solution
g - Using the formula $\alpha = \frac{\theta}{Lc}$, calculate the

Specific rotation of the sugar solution.

g - Repeat the experiment by filling 10%, 15%, and 20% of solution in sample tube by dissolving 10 g, 15 g, and 20 g of sugar in 100 ml of water

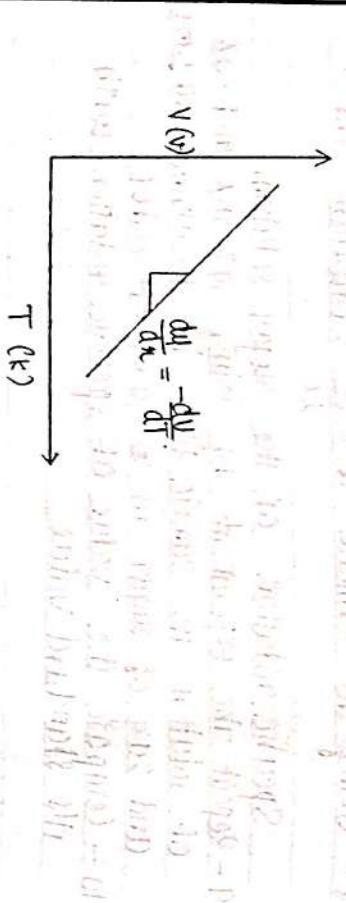
h - Compare the value of specific rotation with its standard value

RESULT

The specific rotation of sugar solution $\alpha = 68.38^{\circ}(\text{gluc})^1(\text{dm})$
Error percentage = 0.82%

The specific rotation of sugar solution from graph,
 $\alpha = 65^{\circ}(\text{gluc})^1(\text{dm})$
Error percentage = 2.25%

EXPECTED V-T CURVE



EXPERIMENT 7 DATE - 3/5/2004

BANDGAP - SEMICONDUCTOR DIODE

AIM

To determine bandgap energy of silicon diode.

APPARATUS REQUIRED

Silicon diode, Beaker, Thermometer, Voltmeter, Ammeter, water Energy band gap kit

THEORY

The bandgap energy of a semiconductor is a fundamental parameter that defines the energy difference between the valence band and the conduction band. The ideal diode equation provides a basis for experimentally determining the bandgap energy through the temperature dependence of the reverse saturation current, which is a small, constant current that flows through a diode when it is reverse biased.

The ideal diode equation describes the current (I) flowing through a diode as a function of the applied voltage (V). It is given by,

$$I = I_0 [e^{\frac{qV}{kT}} - 1] \quad (1)$$

where,

OBSERVATIONS AND CALCULATION

EXPLANATION

$$\frac{dV}{dT} = -3.2 \times 10^{-3} \text{ V/K}, \quad m = 3, \quad n = 2, \quad q = 1.602 \times 10^{-19} \text{ C}$$

Experimental value, Eq = $\sqrt{-T \frac{dV}{dT} - \frac{q}{n k T}}$

$$\text{Theoretical value, Eq} = 1.17 - \frac{4.73 \times 10^4 T^2}{T + 636}$$

$$k = 8.61 \times 10^{-5} \text{ eV/K.} = 1.38 \times 10^{23} \text{ J/K.}$$

Temperature T $^{\circ}\text{C}$	Temperature T K	Voltage (V)	Heating	Cooling	Average	Experimental Eg (eV)	Theoretical Eg (eV)
35	308	0.435	0.417	0.426	1.252	1.122	
40	313	0.419	0.401	0.410	1.249	1.121	
45	318	0.401	0.384	0.392	1.245	1.119	
50	323	0.380	0.364	0.372	1.238	1.118	
55	328	0.358	0.356	0.357	1.237	1.117	
60	333	0.334	0.340	0.337	1.230	1.116	
65	338	0.315	0.330	0.322	1.228	1.114	
70	343	0.297	0.315	0.306	1.226	1.113	
75	348	0.279	0.299	0.289	1.223	1.112	
80	353	0.265	0.269	0.267	1.214	1.110	
85	358	0.248	0.252	0.250	1.210	1.109	
90	363	0.232	0.247	0.239	1.213	1.108	

$$\text{Mean theoretical value} = \underline{\underline{1.115}} \text{ eV}$$

$$\text{Mean experimental value} = \underline{\underline{1.120}} \text{ eV}$$

I - The diode current

I_0 - Reverse saturation current

q - Charge of the electron = $1.602 \times 10^{-19} \text{ C}$

V - Applied voltage across the diode

n - Ideality factor (typically between 1 and 2 for silicon diodes)

k - Boltzmann constant = $8.61 \times 10^{-5} \text{ eV/K}$

T - Absolute temperature in Kelvin

When the forward voltage (V) across the diode is significantly larger than the thermal voltage $\frac{kT}{q}$,

$$\frac{qV}{n k T} \gg 1$$

$$\text{Then, } \frac{qV}{n k T} \gg 1$$

then equation ① can be reduced to,

$$T = T_0 e^{\frac{qV}{n k T}} \quad ②$$

The reverse saturation current is usually too small & to be measured directly.

An indirect graphical method may be obtained by taking logarithm of equation ②, we get

$$\ln T = \ln T_0 + \frac{qV}{n k T} \quad ③$$

$$\ln T \propto \frac{1}{T}$$

T vs V is plotted against $\ln T$. A straight line is obtained

This line intersects the current I axis at T_0 and its slope may be solved to find m .

$$m = \frac{q}{kT} \frac{\Delta V}{\Delta T}$$

T is the temperature in Kelvin, we can take Standard reference temperature as room temperature (300 K)

m decreases as temperature increases. Here we are doing the experiment under constant current and we can take $m = 2$ for Silicon

The study of the bandgap structure of semiconductors is also important because it is directly proportional to its electric properties. It has been observed that experimentally, within a certain temperature range, the relation between temperature and voltage is almost linear. This proportionality can be used to determine the band gap.

The reverse saturation current I_0 for a diode can be expressed as:

$$I_0 = kT^m e^{-\frac{qE_g}{kT}} \quad (4)$$

From graph

$$\frac{dy}{dx} = \frac{dV}{dT} = \frac{0.346 - 0.39}{335 - 330} = 3.2 \times 10^3 \text{ V/K}$$

where,
 k - constant that depends on the material and
 q - geometry of the diode
 T - absolute temperature in Kelvin.
 m - Empirical factor, often close to 3 for silicon
 E_g - Energy band gap.

Voltage (V)

Scale
Range (cm) = 5 cm.
Jacob (J) = 0.004 V

If the current I at T_0
is to be solved to find n ,

 $\frac{\Delta V}{\Delta T}$

Here in Kelvin, we can take standard value as room temperature (300 K)

Temperature increases. Here we are doing under constant current and we can for silicon

The bandgap structure of semiconductor because it is directly proportional electric properties. It has been observed

ally, within a certain temperature range between temperature and voltage. This proportionality can be used to band gap.

Intrinsic current I_0 for a diode can

$$I = I_0 e^{\frac{-qE_g}{kT}} \quad (4)$$

Temperature \rightarrow
(K)

From graph

$$\frac{dy}{dx} = \frac{\Delta V}{\Delta T} = \frac{0.346 - 0.33}{335 - 330} = 3.2 \times 10^3 \text{ V/K}$$

Graph showing $\ln(V/I)$ vs V for
diode showing all values

- where
- k - Constant that depends on the material and geometry of the diode
 - T - Absolute temperature in Kelvin.
 - m - Empirical factor, often close to 3 for silicon
 - Eq - Energy band gap.

CALCULATION

Band gap energy at 308 K

$$\text{Theoretical value } E_g = 1.17 - \frac{4.73 \times 10^4 T^2}{T + 636}$$

$$= 1.17 - \frac{4.73 \times 10^4 (308)^2}{308 + 636}$$

$$= 1.122 \text{ eV}$$

$$\text{Experimental value } E_g = V - \frac{dV}{dT} - \frac{m k T}{q}$$

$$= 1.4116 + \left[\frac{308 \times 3.2 \times 10^{-3}}{1.602 \times 10^{-19}} \right] - \left[\frac{3 \times 2 \times 1.38 \times 10^{-23} \times 308}{1.602 \times 10^{-19}} \right]$$

$$= 1.252 \text{ eV}$$

Error percentage at 308 K

$$= \frac{1.252 - 1.122}{1.122} \times 100$$

we have the diode forward current I , given by

$$I = I_0 e^{\frac{qV}{nKT}}$$

Substitute for I_0 from eq(4)

$$I = k T^n e^{\frac{-qEg}{nKT} - \frac{q(V-Eg)}{nKT}}$$

$$= k T^n e^{\frac{q(V-Eg)}{nKT}}$$

Take logarithm,

$$\ln I = \ln k + m \ln T + \frac{q(V-Eg)}{nKT}$$

At constant current, differentiate the above with respect to T

$$\frac{d}{dT} \ln I = \frac{d}{dT} \left[\frac{q(V-Eg)}{nKT} \right]$$

$$0 = 0 + \frac{m}{T} + \frac{q}{T} \frac{dV}{dT} - \frac{q(V-Eg)}{nKT^2}$$

Multiplying with $\frac{nKT^2}{q}$ we get,

$$0 = \frac{nKT^2 m}{q} + T \frac{dV}{dT} - (V-Eg)$$

$$E_g = V - T \frac{dV}{dT} - \frac{m k T}{q} \quad (5)$$

where, the slope of $V-T$ curve is the temperature coefficient of the junction voltage.

Mean theoretical value, $E_g = 1.115 \text{ eV}$
 Mean Experimental value, $E_g = 1.230 \text{ eV}$

$$\text{Error percentage} = \frac{1.23 - 1.115}{1.115} \times 100$$

$$= 10.3\%$$

The junction gradient coefficient α for silicon is typically given in units of eV/K and describes the rate at which the bandgap energy changes with temperature. It is derived from the temperature dependence of the band gap energy using the Varshini equation:

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta}$$

where,

$E_g(0)$ — The band gap energy at absolute zero temperature
 α — Junction gradient coefficient
 β — Material specific constant.

For silicon,

$$\begin{aligned} E_g(0) &\approx 1.17 \\ \alpha &\approx 4.73 \times 10^{-4} \text{ eV/K} \\ \beta &\approx 636 \text{ K} \end{aligned}$$

$$\therefore E_g(T) = 1.17 - \frac{4.73 \times 10^{-4} T^2}{T + 636} \quad (6)$$

PROCEDURE

- 1 — Connect the silicon diode in reverse bias using a power supply.
- 2 — Take water in a beaker and heat it in burner. It can be used as water bath to study temperature variation.
- 3 — The Energy band gap kit is provided with probe connecting with diode is dipped in the beaker.

3- A diode junction is immersed in water bath. The temperature of water bath is measured with a digital thermometer. The junction is connected to a DC power supply.

Procedure

To determine the value of band gap energy, a constant current is passed through the diode and the voltage developed across the junction is measured for every 5°C rise in temperature.

- 6- A graph of V versus T is plotted with temperature along x -axis and voltage along y -axis.
- 7- The slope dv/dT is determined and using equation ⑤, the experimental value of bandgap energy is determined for each temperature and voltage.
- 8- Comparing the experimental value of E_g with the theoretical value obtained by the equation ⑥
- 9- The experiment is repeated for cooling.

RESULT

The bandgap energies are calculated at different temperatures and Experimental values are compared with theoretical value

$$\text{Mean Theoretical Value } E_g = 1.115 \text{ eV}$$

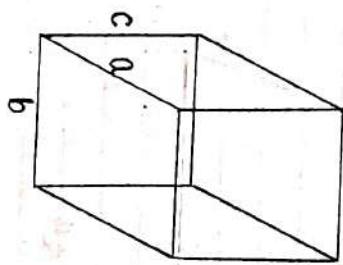
$$\text{Mean Experimental Value } E_g = 1.230 \text{ eV}$$

$$\text{Error percentage} = 10.3\%$$

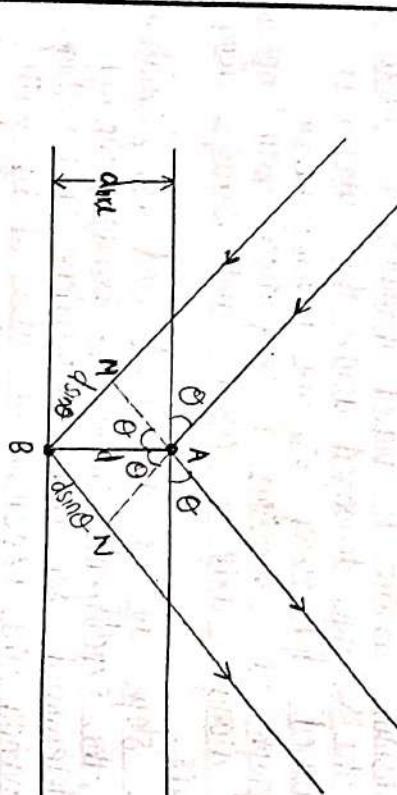
$$\checkmark \frac{1.115}{1.230} \times 100$$

1- A diode junction is immersed in water bath. The temperature of water bath is measured with a digital thermometer. The junction is connected to a DC power supply.

X-RAY DIFFRACTION



UNIT CELL



$$\text{path difference} = MB + BN$$

$$= dsin\theta + dsin\theta$$

$$= 2dsin\theta.$$

THEORY

XRD date of aluminum powder sample

REQUIREMENTS

Using X-ray diffraction data to calculate lattice parameters of some common material (Aluminum powder) with cubic structure.

EXPERIMENT 8

DATE - 8/15/2024

XRD - CRYSTAL STRUCTURE DETERMINATION

X-ray diffraction is a powerful technique used to study the structure of crystalline materials. When X-rays interact with a crystalline sample they are scattered by the atoms within the crystal lattice as shown in the figure. The scattering occurs due to the periodic arrangement of atoms, which act as scattering centers for the incident X-rays. This scattering phenomenon produces constructive interference in certain directions, resulting in diffraction peaks observed on a detector. These diffraction patterns can be analyzed to determine the crystal structure and lattice parameters.

The fundamental principle governing X-ray diffraction is Bragg's law, which relates the wavelength of the incident X-rays, the angle of incidence, and

2θ degree	θ degree	$\sin\theta$	$\sin^2\theta$	$\frac{\sin^2\theta_n}{\sin^2\theta_1}$	$h^2+k^2+l^2$	hkl	$d_{hkl} = \frac{n\lambda}{2\sin\theta}$ (m)	$a = d_{hkl}\sqrt{h^2+k^2+l^2}$ $\times 10^{-10}$ (m)
38.497	19.2485	0.32966	0.10867	1	3	111	2.297×10^{-10}	4.0502
44.749	22.3745	0.38065	0.14489	1.33333	4	200	1.989×10^{-10}	3.979
65.115	32.5575	0.53814	0.28959	2.66485	8	220	1.407×10^{-10}	3.9808
78.239	39.1195	0.63093	0.39807	3.66310	11	311	1.200×10^{-10}	3.9814
82.447	41.2235	0.65899	0.49426	3.99613	12	222	1.1493×10^{-10}	3.9814

Mean lattice parameter $a = 3.9945 \times 10^{-10}$ m

Lattice parameter of Al powder $a = 4.0479 \times 10^{-10}$ m

QUESTION

the interplanar spacing of the crystal planes.

Bragg's law is given by:

$$n\lambda = 2d\sin\theta \quad (1)$$

where,

n - Order of diffraction, usually $n=1$

λ - Wavelength of the X-rays

d - Interplanar spacing

θ - Angle of incidence/Bragg angle.

When X-rays hit the crystal planes at an angle θ , constructive interference occurs if the path difference between the waves scattered from successive planes equals an integer multiple of the wavelength. This results in a diffraction peak at angle θ .

The planes in a crystal are described by Miller indices, denoted as (hkl) . For a cubic crystal, the interplanar spacing d_{hkl} is related to the lattice parameter 'a' and the Miller indices by:

$$d_{hkl} = \frac{a}{\sqrt{h^2+k^2+l^2}} \quad (2)$$

By measuring the diffraction angles 2θ and applying Bragg's law, the interplanar spacing (d) can be determined.

$$\text{From } (1) \quad d_{hkl} = n\lambda \quad (3)$$

Ameter:

$$d \propto \sqrt{h^2 + k^2 + l^2} \quad (4)$$



$$d = \sqrt{h^2 + k^2 + l^2} \cdot \sin\theta \quad (5)$$

From (3), we get

$$\frac{d}{a} = \sqrt{h^2 + k^2 + l^2} \cdot \sin\theta$$

and clear peak from the XRD

value and find θ value.

Miller indices and note down value

of distance d_{hkl} ; using equation (3) parameter 'a' of sample using ion (A) or (B).

$$\text{Copper } K\alpha \lambda = 1.5418 \text{ Å}$$

~~At powder with cubic structure~~

m

$$a = \frac{1.5418 \times 10^{-10} \sqrt{3}}{2 \times 0.6303} = \underline{3.9814 \times 10^{-10} \text{ m}}$$

$$\textcircled{1} \quad \frac{\sin^2 \theta}{\sin^2 \theta_1} = 3.9814^2 = \frac{12}{3}, \quad h^2 + k^2 + l^2 = 12, \quad a = \frac{1.5418 \times 10^{-10} \sqrt{2}}{2 \times 0.6303} = \underline{3.9814 \times 10^{-10} \text{ m}}$$

$$\frac{E_1}{E_0} = \frac{0.16867}{0.16867} = 1 = \frac{2}{3}$$

$$h^2+k^2+l^2 = 3 \quad (\text{iii})$$

$$h^2 = \frac{n^2}{\sin \theta} = \frac{1.5419 \times 10^{-10}}{0 \times 0.32966} = 2.3389 \times 10^{-10} \text{ m}$$

$$a = d_{hk}\sqrt{h^2+k^2+l^2} = 2.3389 \times 10^{-10} \sqrt{3} = 4.0502 \times 10^{-10} \text{ m}$$

$$\frac{S^2}{c_1} = 1.3333 = \frac{4}{3}$$

$$k^2+l^2 = \frac{4}{3} \quad (\text{iv})$$

$$= \frac{n^2}{\sin \theta} \sqrt{h^2+k^2+l^2} = \frac{1.5419 \times 10^{-10}}{0 \times 0.32966} \sqrt{4} = 3.979 \times 10^{-10} \text{ m}$$

$$\frac{S^2}{c_1} = 2.66485 = \frac{8}{3}$$

$$k^2+l^2 = 8 \quad (\text{v})$$

$$= \frac{1.5419 \times 10^{-10}}{2 \times 0.32966} \sqrt{8} = \frac{3.9803 \times 10^{-10}}{2 \times 0.32966} \text{ m}$$

$$\frac{\theta_4}{c_1} = 3.6630 = \frac{11}{3}, \quad h^2+k^2+l^2=11$$

$$a = \frac{1.5419 \times 10^{-10} \sqrt{11}}{2 \times 0.32966} = \frac{3.9814 \times 10^{-10}}{2 \times 0.32966} \text{ m}$$

$$\frac{2.66485}{2 \times 0.32966} = 3.9813 = \frac{12}{3}, \quad h^2+k^2+l^2=12, \quad a = \frac{1.5419 \times 10^{-10} \sqrt{12}}{2 \times 0.32966} = \frac{3.9814 \times 10^{-10}}{2 \times 0.32966} \text{ m}$$

From ② . Lattice parameter:

$$a = d_{hk}\sqrt{h^2+k^2+l^2}. \quad (4)$$

Substitute for d_{hk} from ③ . we get

$$a = \frac{n^2}{\sin \theta} \sqrt{h^2+k^2+l^2}. \quad (5)$$

PROCEDURE

- 1 - Identify sharp and clear peak from the given pattern of XRD.
- 2 - Note down 2θ value and find θ value.
- 3 - determine the Miller indices and note down value for each peak
- 4 - Find interplanar distance d_{hk} using equation ③
- 5 - find the lattice parameter 'a' of sample using appropriate equation (4) or (5)

RESULT

Lattice parameter of Al powder with cubic structure

$$a = 3.9945 \times 10^{-10} \text{ m}$$



OBSERVATION AND CALCULATIONS

2θ degree	θ degree	$\sin\theta$	$\sin^2\theta$	$\frac{\sin^2\theta_1}{\sin^2\theta}$	$h^2+k^2+l^2$	[hkl]	$d_{hkl} = \frac{n\lambda}{\sin\theta}$ $\times 10^{-10} \text{ m}$	$a = d_{hkl} \sqrt{h^2+k^2+l^2}$ $\times 10^{-10} \text{ m}$
28.362	14.181	0.2449	0.0599	1	3	111	3.0926	5.366
47.090	23.545	0.3994	0.1595	2.6627	8	220	1.8963	5.363
55.849	27.924	0.4682	0.2192	3.6594	11	311	1.6176	5.365
68.739	34.369	0.5645	0.3186	5.3188	16	400	1.3417	5.366
75.914	37.957	0.6150	0.3782	6.3138	19	331	1.2315	5.368
76.218	39.109	0.6308	0.3979	6.6427	20	20	1.2006	5.369

Mean lattice parameter $a = 5.3645 \times 10^{-10} \text{ m}$

The lattice parameter of CaF_2 unit cell, $a = 5.451 \text{ \AA} = 5.451 \times 10^{-10} \text{ m}$

EXPERIMENT 9

DATE - 01/05/2024

XRD-LATTICE PARAMETER MEASUREMENTS

AIM

To determine lattice parameter of a crystalline sample (CaF_2) using XRD data

REQUIREMENTS

XRD data of CaF_2 crystalline sample.

THEORY

X-ray diffraction is a powerful technique used to analyze the structure of crystalline materials. When X-rays are incident on a crystal, they are diffracted according to Bragg's law:

$$n\lambda = 2d \sin\theta \quad (1)$$

where,

n - Order of diffraction, usually equal to one

λ - wavelength of the X-rays

d - interplanar spacing

θ - angle of incidence.

When X-rays hit the crystal planes at an angle θ , constructive interference occurs if the path difference the waves scattered from successive planes equals an integer multiple of the wavelength. This results in a

$$\textcircled{1} \quad \frac{\sin^2 \theta}{\sin^2 \theta_1} = 1 = \frac{g}{3}, \quad h^2 + k^2 + l^2 = 3$$

$$d_{hkl} = \frac{n\lambda}{\sin \theta} = \frac{1.5148 \times 10^{-10}}{\sin 0.2449} = 3.0926 \times 10^{-10} \text{ m}$$

$$a = d_{hkl} \sqrt{h^2 + k^2 + l^2} = 3.0926 \times 10^{-10} \sqrt{3} = 5.356 \times 10^{-10} \text{ m}$$

$$\textcircled{2} \quad \frac{\sin^2 \theta}{\sin^2 \theta_1} = 2.6627 = \frac{g}{3}, \quad h^2 + k^2 + l^2 = 8$$

$$d_{hkl} = \frac{1.5148 \times 10^{-10}}{3 \times 0.3994} = 1.8963 \times 10^{-10} \text{ m}$$

$$a = 1.8963 \times 10^{-10} \sqrt{8} = 5.363 \times 10^{-10} \text{ m}$$

$$\textcircled{3} \quad \frac{\sin^2 \theta}{\sin^2 \theta_1} = 3.6594 = \frac{g}{3}, \quad h^2 + k^2 + l^2 = 11$$

$$d_{hkl} = \frac{1.5148 \times 10^{-10}}{3 \times 0.4682} = 1.6146 \times 10^{-10} \text{ m}$$

$$a = 1.6146 \times 10^{-10} \sqrt{11} = 5.365 \times 10^{-10} \text{ m}$$

$$\textcircled{4} \quad \frac{\sin^2 \theta_4}{\sin^2 \theta_1} = 5.3188 = \frac{16}{3}, \quad h^2 + k^2 + l^2 = 16$$

$$d_{hkl} = 1.5148 \times 10^{-10} = \frac{1.3417 \times 10^{-10}}{2 \times 0.5645} \text{ m}$$

$$a = 1.3417 \times 10^{-10} \sqrt{16} = 5.366 \times 10^{-10} \text{ m}$$

diffraction peak at angle 2θ

The planes in a crystal are described by Miller indices

Dhkl

For a cubic crystal, the interplanar distance d_{hkl} is related to the lattice parameter 'a' and the Miller indices by

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}} \quad \textcircled{2}$$

By measuring the diffraction angle 2θ and applying Bragg's law, the interplanar distance can be determined.

i.e., from $\textcircled{1}$ $d_{hkl} = n\lambda / \sin \theta$ $\textcircled{3}$

$$\text{And from } \textcircled{2} \quad a = d_{hkl} \sqrt{h^2 + k^2 + l^2}$$

$$a = n\lambda \sqrt{h^2 + k^2 + l^2} / \sin \theta$$

$$a = n\lambda \sqrt{h^2 + k^2 + l^2} / \sin \theta$$

PROCEDURE

- Identify sharp and clear peak from the given pattern of XRD
- Note down 2θ value and find θ value.
- Determine the Miller indices and notedown value for each peak
- Find interplanar distance d_{hkl} using Bragg's law.

Counts

CatZ Cat

8000

6000

4000

2000

0

(%) 100 [°] 28.362

Position [2Theta]

47.090 [°]; 54 [%]

55.849 [°]; 22 [%]

68.739 [°]; 6 [%]

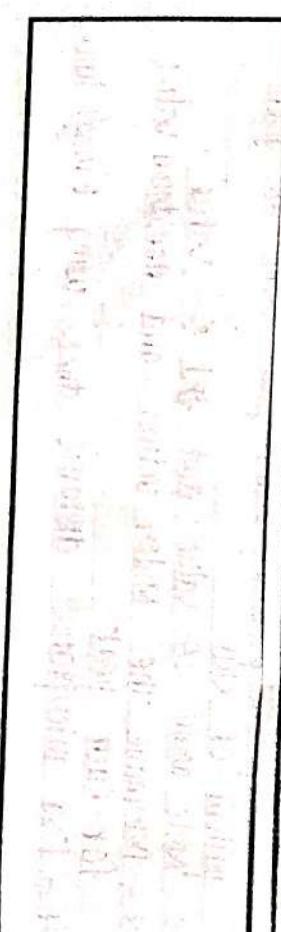
75.914 [°]; 10 [%]

78.218 [°]; 1 [%]

parameters 'a' of given sample
in equation.

ANAL

18
dihydrated and lattice parameters
 $3.645 \times 10^{-10} \text{ m}$



QUESTION

EXPERIMENT

b - Find the lattice parameter 'a' of given sample using appropriate equation.

RESULT

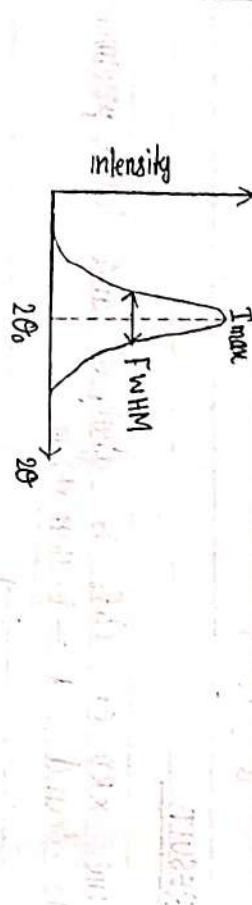
The XRD of CaF_2 is analysed and lattice parameter is found, $a = 5.3645 \times 10^{-10} \text{ m}$

~~ANSWER~~

QUESTION

EXPERIMENT

RESULT



EXPERIMENT 10

DATE - 10/5/24

XRD - DETERMINATION OF CRYSTALLITE SIZE AND LATTICE STRAIN

AIM

To determine the crystallite size and lattice strain of a given crystalline sample using X-ray diffraction data.

REQUIREMENTS

XRD of the Sample

THEORY

In XRD data, the broadening B_p at peaks is due to the combined effect of crystallite size B_s and microstrain β_s . i.e,

$$B_p = \beta_s + \frac{B_s}{\cos \theta} \quad (1)$$

Scherrer equation is used to calculate crystallite size and average crystallite size from XRD data.

From the Scherrer equation, we have,

$$\beta_s = K \frac{1}{D \cos \theta} \quad (2)$$

OBSERVATION AND CALCULATIONS

O. THERMOMETER

$$\text{D} = \frac{k\lambda}{\beta g \sin\theta} \quad (3)$$

θ degree	θ radian	FWHM(β) degree	FWHM(β) radian	$\beta \cos\theta$	$k \sin\theta$
29.295	0.514575	0.194561	0.274	0.004782	0.004692
27.886	0.4818	0.242415	0.216	0.008752	0.008642
31.63	0.5315	0.276024	0.268	0.009713	0.009632
32.578	0.5299	0.28451	0.212	0.0037	0.003651
39.347	0.6735	0.343864	0.255	0.004451	0.004191
46.069	0.73045	0.402028	0.243	0.004241	0.003903

θ degree	θ radian	FWHM(β) degree	FWHM(β) radian	$\beta \cos\theta$	$k \sin\theta$
16.299	0.28451	0.212	0.212	0.0037	0.003651
1.1226	1.1226	1.1226	1.1226	1.1226	1.1226
1.346639	1.346639	1.346639	1.346639	1.346639	1.346639

θ degree	θ radian	FWHM(β) degree	FWHM(β) radian	$\beta \cos\theta$	$k \sin\theta$
19.6335	0.343864	0.255	0.255	0.004451	0.004191
1.565141	1.565141	1.565141	1.565141	1.565141	1.565141
1.846639	1.846639	1.846639	1.846639	1.846639	1.846639

where,
 β_B - Broadening due to crystallite size.
 k - Shape factor or Scherrer constant, typically 0.9.
 λ - wavelength of x-ray = 1.5418×10^{-10} m
 D - Crystallite size
 θ - Bragg angle in radian

Similarly, broadening due to microstrain is given by:

$$\beta_E = 4E \tan\theta \quad (4)$$

where,
 E is the strain

Combining equations (1), (2) and (4)

$$\beta_D = \frac{k\lambda}{D} + \frac{4E \tan\theta}{\cos\theta} \quad (5)$$

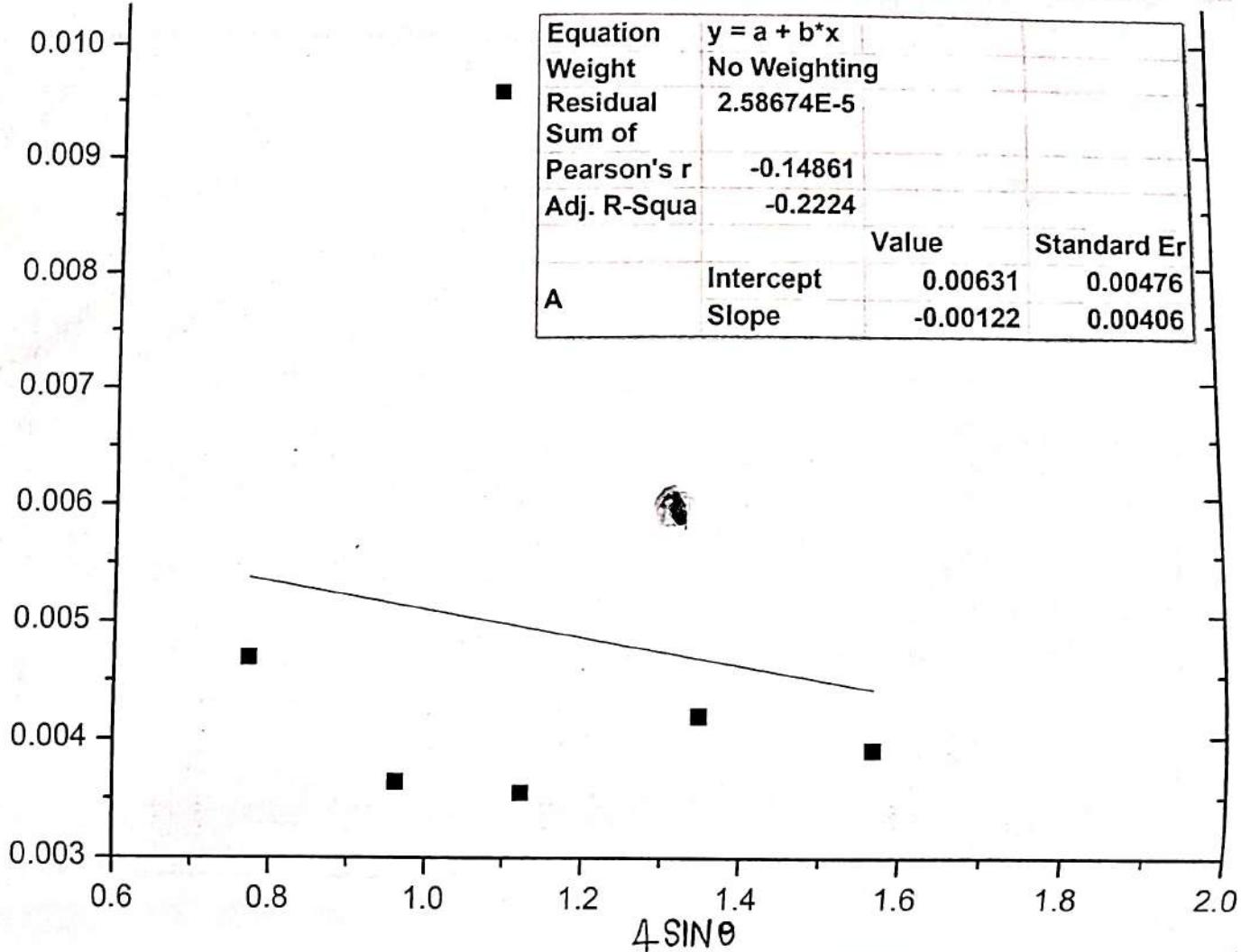
$$\beta_D = k\lambda \sec\theta + 4E \sin\theta$$

Multiply throughout by $\cos\theta$.

$$\beta_D \cos\theta = k\lambda \sec\theta \cos\theta + 4E \sin\theta \cos\theta \quad (6)$$

Equation (6) is similar to the equation of a straight line, $y = mx + c$

$\theta \text{ cos } \theta$



where,
 m - slope of the straight line
 c - y intercept

Comparing (6) and (7), we can write;

$$y = B_D \cos \theta \quad (8)$$

(9)

$$m = \frac{c}{D} \quad (10)$$

D

WILLIAMSON-HALL PLOT

plot $B \cos \theta$ on the Y axis against $4 \sin \theta$ on the X axis. Fit a straight line to the data points. Such a plot is called Williamson-Hall plot. From the Y intercept (c), we can calculate the crystallite size (D) using equation (10). The slope (m) of the line gives the lattice strain (ϵ)

PROCEDURE

- 1 - Note down 2θ values and FWHM values of the sample given.
- 2 - Convert 2θ to θ and degrees to radian.
- 3 - convert FWHM (β) from degrees to radian.
- 4 - calculate $B \cos \theta$ and $4 \sin \theta$.
- 5 - plot $B \cos \theta$ on the Y axis against $4 \sin \theta$ on the X axis and fit a straight line to the data points using software OriginLab.
- 6 - Record the Y-intercept (c) and calculate the crystallite size (D) using equation (10)

From plot

$$\text{slope } \epsilon = 0.00122.$$

$$\text{Grain size } D = \frac{k\lambda}{c} = \frac{0.9 \times 1.514 \times 10^{-10}}{0.00681} = 2.219 \times 10^{-8} \text{ m}$$

- # - Record the slope of the line, which gives the lattice strain (ϵ).

PLOTTING PROCEDURE IN ORIGINLAB

- 1 - Import your data from Excel file or textfile into Origin lab.
- 2 - Ensure your data is in two columns: using β and $\cos \theta$.
- 3 - Highlight the columns of data by selecting.
- 4 - From the menu bar options given in the lower portion of the lab select the scatter option for plotting.
- 5 - This will create a scatter plot with using in the x axis and ~~beta~~ on the y axis.
- 6 - With the scatter plot active go to Analysis menu and select Fitting > Linear fit > open dialogue.
- 7 - Click OK to fit the data.
- 8 - Originlab will add a fitted line to the scatter plot and display the fitting parameters, which include the slope (m) and y intercept (c).

RESULT

The XRD of given sample is analyzed. The crystallite size and lattice strain obtained

$$\text{Lattice strain } \epsilon = 0.0012$$

$$\text{Crystallite size } D = 2.219 \times 10^{-8} \text{ m}$$

USING CONSTANTS AND CALCULATION, CONVERSION

$$h = 6.626 \times 10^{-34} \text{ Js}$$

$$c = 3 \times 10^8 \text{ m/s}$$

$$1 \text{ J} = 6.242 \times 10^{18} \text{ eV}$$

$$1 \text{ m} = 10^9 \text{ nm}$$

$$h\nu = \frac{hc}{\lambda}$$

$$hc = 6.626 \times 10^{-34} \text{ Js} \times 3 \times 10^8 \text{ m/s} = 1.986 \times 10^{-25} \text{ Jm}$$

To convert Jm to eV.nm .

$$hc = 1.986 \times 10^{-25} \text{ Jm} \times \frac{6.242 \times 10^{18} \text{ eV}}{1 \text{ J}} \times \frac{10^9 \text{ nm}}{1 \text{ m}}$$

$$= 1.986 \times 10^{-25} \text{ Jm} \times 6.242 \times 10^{18} \text{ eV} \times 10^9 \text{ nm}$$

THEORY

REQUIREMENTS

UV-visible absorption date. of MgO

THEORY

UV-visible spectrosocpy measures how much light a material absorbs. This can be done using either absorphion or reflection spectrosocpy. The intensity of light passing through or reflected by a sample is measured, usually in terms of transmittance or absorbance.

Materials absorb light at specific wavelengths corresponding to energy transitions within the material. For semi conductors, the band gap energy is a key value representing the energy difference between the valence bond and the conduction band.

EXPERIMENT 11

DATE - 13/6/24

BAND GAP AND TYPE OF OPTICAL - TRANSITION DIRECT OR INDIRECT USING TAUC

RELATION FROM ABSORPTION SPECTRA

AIM

To determine the band gap energy of a material using UV-visible absorption date with the Tauc plot method.

OBSERVATION AND CALCULATION

RESULTS

1. HgTe HOMO LUMINESCENCE

wavelength (nm)(λ)	absorbance (A)	absorption coeff $\alpha = 2.303 A$	Energy $h\nu = \frac{hc}{\lambda}$	$(\alpha h\nu)^2$	$(\alpha h\nu)^{1/2}$	MATERIAL
1.55	0.001	0.002303	1.96e-19	4.24e-39	6.5e-20	HgTe

wavelength (nm)(λ)	absorbance (A)	absorption coeff $\alpha = 2.303 A$	Energy $h\nu = \frac{hc}{\lambda}$	$(\alpha h\nu)^2$	$(\alpha h\nu)^{1/2}$	MATERIAL
1.55	0.001	0.002303	1.96e-19	4.24e-39	6.5e-20	HgTe

DISCUSSION

In direct band gap semiconductors, the top of the valence band and the bottom of the conduction band occurs at the same momentum value, allowing electrons to directly transition between these bands by absorbing or emitting a photon. For indirect band gaps, the transition involves a change in momentum, typically requiring a phonon in addition to the photon.

The optical band gap of a material can be determined using its absorption spectrum. The absorption coefficient & how the absorption edge is related to the photon energy $h\nu$ by the Tauc relation, which varies depending on whether the optical transition is direct or indirect.

For direct transitions:

$$(\alpha h\nu)^2 = A (h\nu - E_g)$$

For indirect transitions:

$$(\alpha h\nu)^{1/2} = A (h\nu - E_g)$$

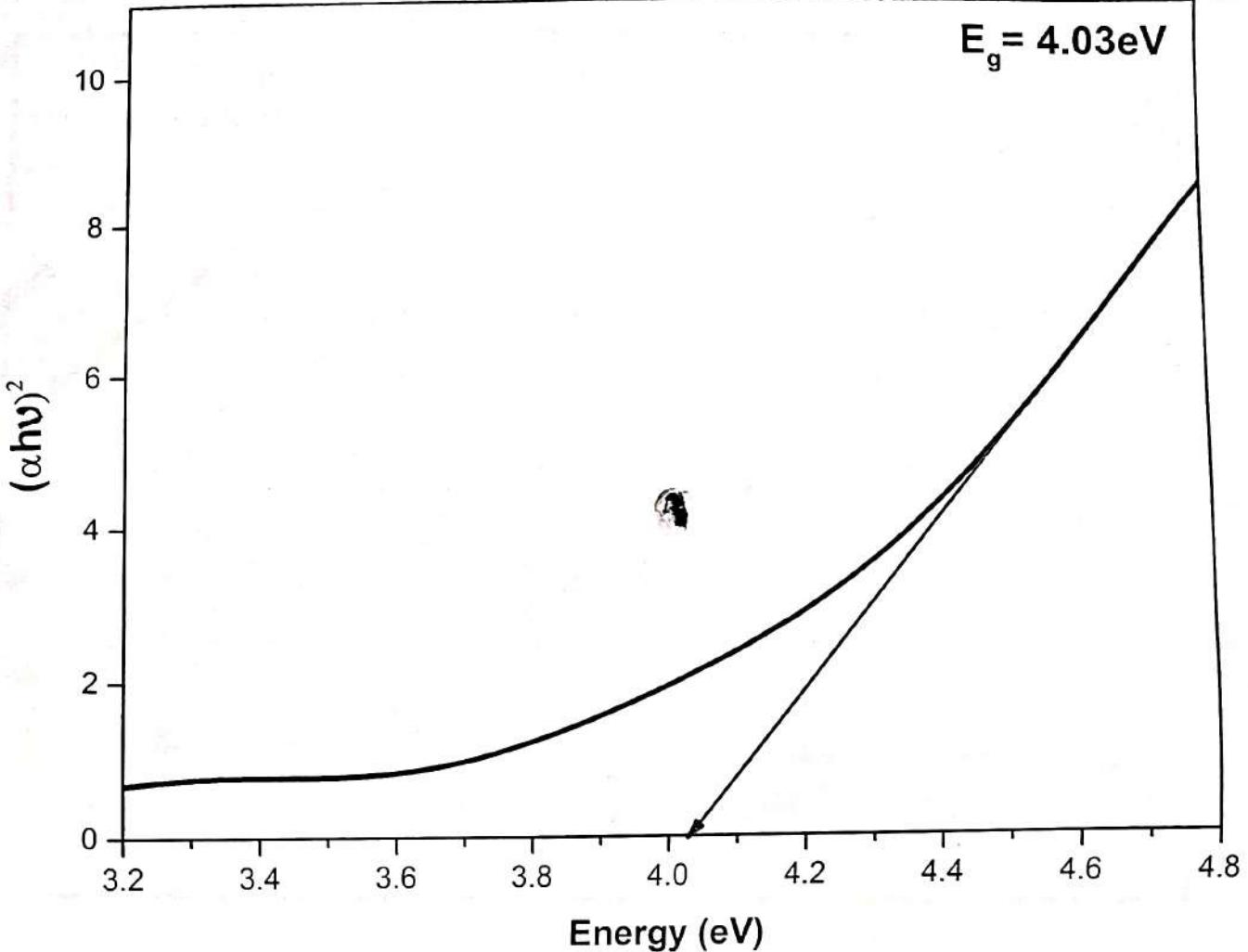
where,
 α – absorption coefficient, $\alpha = 2.303 \times \text{absorbance}$.
 t – thickness of the material

$$h\nu = \text{photon energy}$$

$$E_g = \text{bandgap energy}$$

A – A constant

By plotting $(\alpha h\nu)^2$ vs $h\nu$ for direct transitions on $(\alpha h\nu)^{1/2}$ vs $h\nu$ for indirect transitions, the band gap can be determined from the intercept of



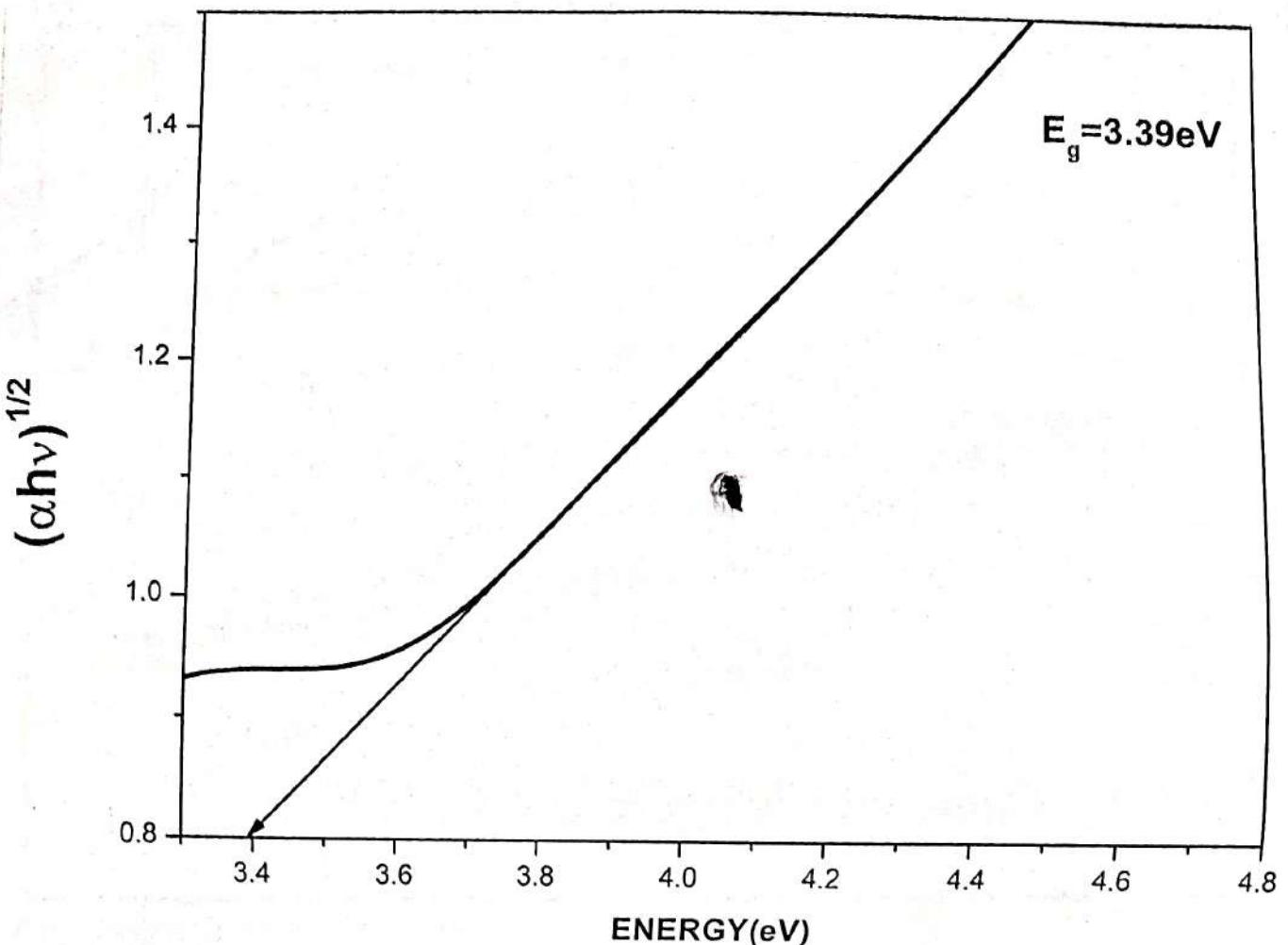
linear portion of the plot with the hv energy axis.

PROCEDURE

- 1 - Record the absorbance (A) and corresponding wavelength (λ)
- 2 - Convert the absorbance (A) to absorption coefficient α using the formula:
$$\alpha = \frac{A}{t} \times 2.303, \quad t = 1\text{cm}$$
- 3 - Convert the wavelength λ to photon energy hv using the formula:
$$\text{hv} = hc = 1240 (\text{eV.nm}) / \lambda (\text{nm})$$

where, h - planck's constant
 c - speed of light.

- 4 - Plot $(\alpha \text{hv})^{1/2}$ versus hv to check for a linear relationship indicating an indirect transition
- 5 - Plot $(\alpha \text{hv})^2$ versus hv to check for a linear relationship indicating an direct transition
- 6 - Fit a straight line to the linear portion of the plot on both plots using OriginLab
- 7 - The intercept on the hv axis gives the band gap energy Eq.



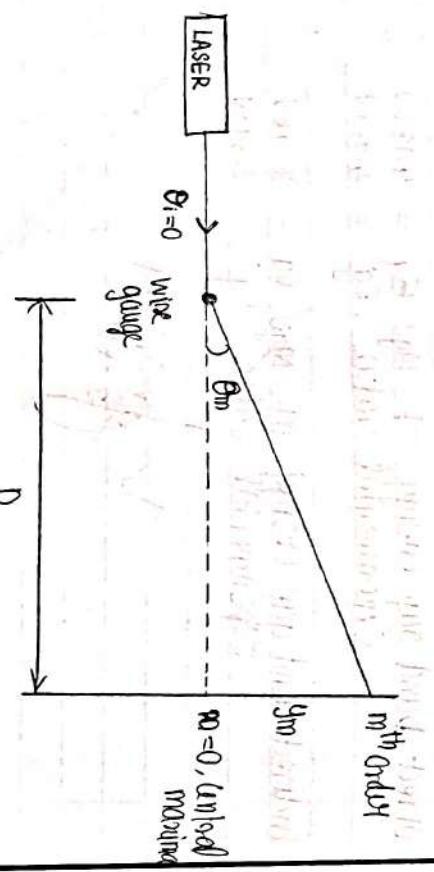
RESULT

Direct band gap energy of MgO , $E_g = 4.18 \text{ eV}$
Experimental value, $E_g = 4.03 \text{ eV}$

Indirect band gap energy of MgO , $E_g = 3.40 \text{ eV}$
Experimental value, $E_g = 3.39 \text{ eV}$

*✓
Final*

LASER DIFFRACTION - COMPARISON OF THICKNESS OF WIRES OF DIFFERENT GAUGES



AIM

To determine the diffraction pattern and to calculate the diameter ' d ' of different gauges.

APPARATUS REQUIRED

Laser, meter scale, different wire gauges, graph paper etc.

THEORY

Diffraction is the phenomenon of bending of light around an obstacle or spreading of light around an obstacle caused by passing through an aperture where the size of the obstacle or a aperture is comparable to the wavelength of light.

Let a monochromatic laser light of wavelength λ is incident normally on an obstacle. As a result it creates a diffraction pattern of bright and dark fringes on a screen which kept at distance D from the wire gauge the obstacle.

Let θ_m be the angle subtended between the central maximum and the m^{th} order maximum. And

OBSERVATIONS AND CALCULATIONS

$$\lambda = 535 \times 10^{-9} \text{ m}$$

DATA

WIRE No.	Order m	Distance from Central maximum				$\theta = \frac{\sin \theta}{D}$	$\sin \theta \times 10^3$	$d = \frac{m \lambda}{\sin \theta} \times 10^3$
		Left	Right	Mean	$\times 10^3$			
I	1	3	3	3	0.0965	1.6842	0.3176	
	2	4.5	4.5	4.5	0.1448	2.5242	0.4233	
	3	6	6	6	0.1931	3.3402	0.4762	
II	1	3.2	3.2	3.2	0.0996	1.7383	0.3047	
	2	4.5	4.5	4.5	0.1401	2.4452	0.4345	
	3	7	7	7	0.2149	3.8020	0.4220	
III	1	6	6	6	0.0944	1.6475	0.3244	
	2	11	11	11	0.1731	3.0211	0.3541	
	3	16	16	16	0.2518	4.3947	0.3652	

y_m be the distance on the screen from the m th order maximum to the central maximum.

The equation for diffraction is given by:

$$d(\sin \theta_m + \sin \theta_i) = m \lambda \quad (1)$$

where,
 d - diameter of the wire.

Since the laser beam is incident normally on the wire, $\theta_i=0$
equation (1) can be reduced to :

$$d \sin \theta_m = m \lambda$$

$$\text{and } d = \frac{m \lambda}{\sin \theta_m} \quad (2)$$

The angle θ_m can be obtained from y_m and D .
From the figure, we can write

$$\tan \theta_m = \frac{y_m}{D}$$

$$\theta_m = \tan^{-1} \frac{y_m}{D} \quad (3)$$

PROCEDURE

- The laser source is switched on and light is allowed to fall normally on the wire gauge.

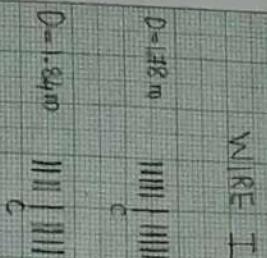
$$\text{Mean diameter of wire I} = 0.394 \times 10^{-3} \text{ m}$$

$$\text{Mean diameter of wire II} = 0.3284 \times 10^{-3} \text{ m}$$

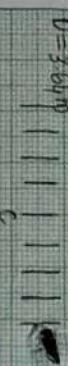
$$\text{Mean diameter of wire III} = 0.5382 \times 10^{-3} \text{ m}$$

$$\lambda = 535 \times 10^{-9} \text{ m}$$

WIRE I



WIRE II



RESULT

The diameter or thickness of different gauge wires are calculated.

$$\text{diameter of wire I} = 0.3943 \times 10^{-3} \text{ m}$$

$$\text{diameter of wire II} = 0.3287 \times 10^{-3} \text{ m}$$

$$\text{diameter of wire III} = 0.5382 \times 10^{-3} \text{ m}$$

WIRE III



WIRE III

- WIRE I WIRE II WIRE III WIRE IV WIRE V

Completed



FEB 28

To Sir
Dr. V. G. M. M.
J. C. D.

Dear Sir
I am sending you
the report of my
visit to the
University of
Tunis. It will
be forwarded
to you by
post.

Yours very
obediently
L. C. D.

Yours very
obediently
L. C. D.

A. J. D. Wilson

1/1/26

1/1/26