Expt. No. ______ ① AN 25/04/22 Date 25/4/22

Page No. ______

Experiment - 1

Aim

Estimation of Error in measurements of Vernier Callipers & Screw Gauge.

Apparatus

Vernier Callipers, Screw Gauge, metal ball, metal ring, weighing machine

Theory

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$T = t/10$$

$$g = \frac{4\pi^2 l}{T^2}$$

$$\ln(g) = \ln(4) + 2\ln(\pi) + \ln(l) - 2\ln(T)$$

$$\frac{dg}{g} = 0 + 0 + \frac{dl}{l} - 2\frac{dT}{T} = \frac{dl}{l} - 2\frac{dT}{T}$$

$$\frac{dg}{g} = \frac{dl}{l} + 2\frac{dT}{T}$$

$$\frac{dg}{g} = \frac{10^{-3}}{0.2} + 2\frac{0.1}{9} \approx 0.005 + 0.02222 \approx 0.027$$

$$g \approx (9.7 \pm 0.3)\, m/s^2.$$

$$\text{Least count} = 1\text{ MSD} \times \left(1 - \frac{\text{Number of MSD}}{\text{Number of VSD}}\right).$$

Teacher's Signature ______

Expt. No. ______ A 28/04/21 Page No. ______

$$V = \frac{4\pi}{3} R^3 = \frac{\pi}{6} D^3$$

$$\ln(V) = \ln\left(\frac{\pi}{6}\right) + 3\ln(D).$$

$$\frac{dV}{V} = 0 + 3\frac{dD}{D}$$

$$= 3\frac{dD}{D}$$

Observations

Least count of Vernier calipers = 0.02 ~~mm~~

Least count of screw gauge = 0.01 ~~cm~~ mm

Least count of weighing scale = 0.1 gm

Table 1: Error in the volume and density of spherical metal ball.

S.No	Diameter (m) ($\times 10^{-3}$)	Avg. Diameter (m)	Avg. Volume (m^3) ($\times 10^{-3}$)	Error in volume (%)	Error in volume (m^3)	Avg. Density (kg/m^3)	Error in density (%)	Error in density (kg/m^3)
1	6.29							
2	6.27							
3	6.30	31.43	97.450	0.423	0.631×10^{-9}	7.493×10^{3}	10.47	7.847×10^{2}
4	6.28							
5.	6.29							

Table 2:

Error in the volume and density of a metal ring.

S.No	Inner/Outer dia (m) ($\times 10^{-3}$)	Avg. Inner / Outer dia (m) ($\times 10^{-3}$)	Thickness (m)	Avg. Volume (m^3)	Error in Volume (%)	Error in volume (m^3)	Avg. Density (kg/m^3)	Error in Density (%)	Error in density (kg/m^3)
1	14/36								
2	15/37		2.16×10^{-3}	1.913×10^{-6}	0.19%	~~[illegible]~~	~~[illegible]~~		
3	13/36	14.2/36.2	~~2%~~				14.6×10^{-3}	1.2%	0.656
4	15/35								
5	14/37								

Calculation :-

a) For sphere :-

1) Avg. volume $= \frac{\pi}{6} D^3$

$$= \frac{\pi}{6} \cancel{\times 3.14} (31.43 \times 10^{-3})^3$$

$$= 97.490 \times 10^{-3} \ m^3$$

2) Error in volume

$$\frac{dV}{V} = \frac{3dD}{D}$$

$$dV = \frac{3 \times V \times dD}{D}$$

$$= \frac{3 \times 9.7490 \times 10^{-3} \times 0.01}{31.43 \times 10^{-3} \times 10^3 \times 10^2}$$

$$= 0.631 \times 10^{-9} \ m^3$$

3) Error in volume (%)

$$\Rightarrow \frac{0.631 \times 10^{-9} \times 100}{97.490 \times 10^{-3}}$$

$$= 0.473\%$$

4) Avg. Density:

$$den = \frac{m}{V} = \frac{0.1g}{97.490 \times 10^{-3}\ m^3}$$

$$= 7.493 \times 10^{3}\ kg/m^3$$

5) Error in Density:-

$$\frac{d(den)}{den} = \frac{dm}{m} + \frac{dV}{V}$$

$$d(den) = den\left(\frac{dm}{m} + \frac{dV}{V}\right)$$

$$= 7.493 \times 10^3\left(\frac{0.0001}{0.001} + 0.631 \times 10^{-9}\right)$$

$$= 0.7847 \times 10^3\ kg/m^3$$

6) For Metal Ring:

Avg. Volume

$$V = \pi h\left(R^2_{out} - r^2_{in}\right)$$

$$= \frac{\pi}{4}\left(D^2_{out} - D^2_{in}\right)h$$

$$= \frac{\pi}{4}\left((36.947 \times 10^{-3})^2 - (14.212 \times 10^{-3})^2\right) \times 2.16 \times 10^{-3}$$

$$= 1.913 \times 10^{-6}\ m^3$$

Result

1. The measured value of steel ball is: $97.490 \times 10^{-3}\ m^3$
2. Value of density of the material of steel ball is: $7.493 \times 10^3\ kg/m^3$
3. The measured volume of steel ring is: $1.913 \times 10^{-6}\ m^3$
4. The measured value of density of steel ring is: $1.300 \times 10^3\ kg/m^3$

9/10

Teacher's Signature

Expt. No. ______ Date 2/5/22

① AA 2/05/22

Page No. ______

Experiment - 2

Aim:

To determine the moment of inertia of a flywheel.

Apparatus:

Fly wheel, weight hangar, slotted weights, stop watch, a meter scale.

Formula Used

$$P_{loss} = mgh$$

$$K_{flywheel} = \frac{1}{2} I \omega^2$$

$$K_{weight} = \frac{1}{2} m v^2.$$

$$W_{friction} = \cancel{m}\, n W_f$$

$$P_{loss} = K_{flywheel} + K_{weight} + W_{friction}$$

$$mgh = \frac{1}{2} I \omega^2 + \frac{1}{2} m v^2 + n W_f$$

$$N W_f = \frac{1}{2} I \omega^2.$$

$$W_f = \frac{1}{2N} I \omega^2.$$

r = radius

v = velocity

$$v = \omega r.$$

Teacher's Signature ______

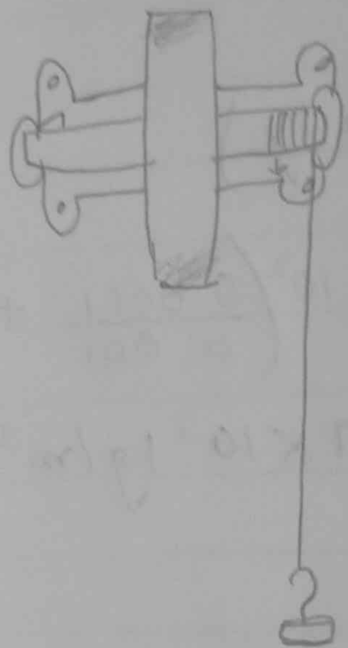

Fig experimental setup

$$mgh = \frac{1}{2} I\omega^2 + \frac{1}{2} mr^2\omega^2 + \frac{n}{N}\left(\frac{1}{2} I\omega^2\right)$$

$$I = \frac{Nm}{N+n}\left(\frac{2gh}{\omega^2} - r^2\right)$$

$$h = 2\pi r n$$

$$W_{average} = \frac{2\pi N}{t}$$

$$\omega = \frac{4\pi N}{t}$$

$$\cancel{I = N}.$$

Observation

Radius of the axle of the flywheel (r) =

Table 1: Calculation of Moment of Inertia of flywheel

S.No	Mass suspended (m in kg)	No. of revolutions n	N	Height of descend before detachment (h in m)	Time for N revolutions (t in s)	Angular velocity (ω in s^{-1})	Moment of Inertia of the flywheel (I in kg-m²)
1	.100	6	4	0.376	14.38	3.493	24.116
2	.150	6	9	0.376	17.96	6.293	16.731
3	.200	6	12	0.376	19.70	7.65	16.775
4	.250	6	15	0.376	22.76	8.277	19.086
5	.300	6	18	0.367	24.24	9.326	18.877

Mean value moment of inertia, $I = 19.117\ kg\,m^2$

Calculation of h (height of descend before detachment)

10 mm in m is 0.01

$$h = 2\pi r n$$
$$= 2(3.14)(0.01)(6)$$
$$= 0.376m$$

Angular velocity (ω)

$$\omega_1 = \frac{4\pi N}{t}$$

$$\omega_1 = \frac{4 \times 3.14 \times 4}{14.38} = 3.493$$

$$\omega_2 = \frac{4 \times 3.14 \times 9}{17.96} = 6.293 \ s^{-1}$$

$$\omega_3 = \frac{4 \times 3.14 \times 12}{19.70} = 7.65 \ s^{-1}$$

$$\omega_4 = \frac{4 \times 3.14 \times 15}{22.76} = 8.274 \ s^{-1}$$

$$\omega_5 = \frac{4 \times 3.14 \times 18}{24.24} = 9.326 \ s^{-1}$$

Moment of inertia of the flywheel (I):

1. $$I_1 = \frac{N_1 m_1}{N_1 + n}\left(\frac{2gh}{\omega_1^2} - r^2\right)$$

$$= \frac{400}{10}\left(\frac{2 \times 9.8 \times 0.326}{(3.493)^2} - 10^{-4}\right)$$

$$= 40\left(\frac{7.369}{12.201} - 10^{-4}\right)$$

$$= 40\left(\frac{0.603 - 0.0001}{40 \times (0.002)}\right)$$

$$I_1 = 24.116 \ Kgm^2$$

2. $$I_2 = \frac{N_2 m_2}{N_2 + n}\left(\frac{17.369}{\omega_2^2} - 10^{-4}\right)$$

$$= \frac{9 \times 150}{13}\left(\frac{7.369}{(6.293)^2} - 0.0001\right)$$

Expt. No.

$$= \frac{1350}{15}\left(\frac{7.369}{39.601} - 0.0001\right)$$

$$= 90\left(0.186 - 0.0001\right)$$

$$= 90 \times 0.1859$$

$$= 16.731 \ kgm^2$$

(3) $$I_3 = \frac{N_3 m_3}{N_3 + n}\left(\frac{7.369}{\omega_3^2} - 10^{-4}\right)$$

$$= \frac{12 \times 200}{18}\left(\frac{7.369}{(7.65)^2} - 10^{-4}\right)$$

$$= 133.33\left(\frac{7.369}{58.52} - 10^{-4}\right)$$

$$= 133.33\left(0.1259 - 10^{-4}\right)$$

$$= 133.33 \times 0.1258$$

$$= 16.775 \ kgm^2.$$

(4) $$I_4 = \frac{N_4 m_4}{N_4 + n}\left(\frac{7.369}{(\omega_4)^2} - 10^{-4}\right)$$

$$= \frac{15 \times 250}{21}\left(\frac{7.369}{(8.277)^2} - 10^{-4}\right)$$

$$= 178.571\left(\frac{7.369}{68.508} - 10^{-4}\right)$$

$$= 178.571\left(0.107 - 10^{-4}\right)$$

$$= 178.571 \times 0.1069.$$

$$= 19.089 \ kg \ m^2.$$

(5) $$I_5 = \frac{N_5 m_5}{N_5 + n}\left(\frac{7.369}{(\omega_5)^2} - 10^{-4}\right)$$

$$= \frac{18 \times 300}{24} \left(\frac{7.369}{(9.326)^2} - 0.0001 \right)$$

$$= 225 \left(\frac{7.369}{86.974} - 0.0001 \right)$$

$$= 225 \left(0.084 - 10^{-4} \right)$$

$$= 225 \times 0.0835$$

$$= 18.877 \text{ Kg m}^2$$

Result

The measured moment of inertia of the flywheel is 19.117×10^{-3} kg m^2.

9/10

Expt. No. 20/05/22

Date

Page No.

Experiment - 3

Aim

Determination of the coefficient of viscosity of glycerin by falling sphere method.

Apparatus Required

Measurement unit, Test liquid: Glycerin, spherical steel balls, stopwatch, long graduated cylinder, weighing scale.

Formula Used

1) $f = 6\pi \eta r v$

2) $F = mg - F_b = \frac{4}{3}\pi r^3 (\rho - \sigma) g$

3) $V_t = \frac{2}{9} r^2 \frac{(\rho - \sigma)}{\eta} g$, when $F = f$

4) $\eta = \frac{2}{9} r^2 t \frac{(\rho - \sigma)}{x} g$

where f = drag force
r = radius of sphere
η = viscosity of the fluid
v = velocity of sphere / V_t = terminal velocity
F_b = buoyant force
F = net driving force
ρ = density of ball
σ = density of liquid

Teacher's Signature

Expt. No. ______ Page No. ______

31/05/22

Observation

Calculation of density of metal sphere

Balls	Mass (gm)	Radii (mm) r_1	r_2	r_3	Average radius of each ball $\frac{r_1+r_2+r_3}{3}$ (mm)	Avg radius of three balls r (mm)	Avg mass of three balls m (gm)	Density of sphere ρ (kg/m³)
A	0.25	1.9 ~~3.8~~	1.85 ~~3.7~~	1.95	1.9			
B	0.25	1.95 ~~3.9~~	1.85 ~~3.7~~	1.9	1.9	1.86	0.25	927.5×10^{21}
C	0.25.	1.8 ~~3.6~~	1.9 ~~3.8~~	1.9	1.8			

Calculation of coefficient of viscosity of glycerin

Balls	Distance (mm)	Time of transit (sec) t_1	t_2	t_3	Mean time (sec) $t = \frac{t_1+t_2+t_3}{3}$ sec	Viscosity (η) (Pas)	mean viscosity (Pas) η
A	150	1.5	1.75 ~~3.05~~	1.63 ~~3.28~~	1.92.	0.788	
B	150	1.63 ~~4.26~~	1.58 ~~3.21~~	1.6 ~~4.81~~	1.60	0.657	0.702.
C	150	1.49	1.59 ~~3.08~~	1.75 ~~4.83~~	1.61	0.661	

Calculation

Density of sphere (ρ)

$$\rho = \frac{M}{V}$$

$$\rho = \frac{0.2 \times 10^{-3}}{26.94 \times 10^{-9}}$$

$= 9275 \ kg/m^3.$

Teacher's Signature ______

$$v = \frac{4}{3} \pi r^3$$

$$= \frac{4}{3} \times 3.14 \times 10^{?}$$

$$= 26.94 \times 10^{-9}$$

Viscosity for ball (A)

$$\eta_A = \frac{2}{9} r^2 t \left(\frac{\rho - \sigma}{x}\right) g$$

$$= \frac{2}{9} (1.86)^2 \times (1.92) \times \left(\frac{9275 - 1260}{0.15}\right) 10$$

$$= 1.476 \times 53433.3 \times 10^{-6} \times 10$$

$$= \cancel{7.88} \; 78867.6 \times 10^{-5}$$

$$= 0.788$$

for Ball (B)

$$\eta_B = \frac{2}{9} r^2 t \left(\frac{\rho - \sigma}{x}\right) g$$

$$= \frac{2}{9} (1.86)^2 \times 10^{-6} \times 1.60 \times (53433.3) \times 10$$

$$= 1.23 \times 10^{-5} \times 53433.3$$

$$= 0.657$$

for Ball (C)

$$\eta_C = \frac{2}{9} r^2 t \left(\frac{\rho - \sigma}{x}\right) g$$

$$= \frac{2}{9} (1.86)^2 \times 10^{-6} \times 1.61 \times 53433.3 \times 10$$

$$= 1.237 \times 10^{-5} \times 53433.3$$

$$= 0.661$$

Mean η

$$= \frac{0.788 + 0.657 + 0.661}{3}$$

$$\boxed{\eta = 0.702} \text{ Poise}$$

Result

The viscosity of the given liquid was measured to 0.702 poise.

9/10

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Date 21/5/22

Expt. No.

Page No.

Experiment - 4

Aim

Determination of Young's modulus of the given sample by method of bending

Apparatus Required

Sample stand, weights of 500gm, Given metal sample, DC adapter, weight Holder, spherometer, stand and Buzzer

Formula Used

$$Y = \frac{\text{Tensile stress}}{\text{Tensile strain}} = \frac{\sigma}{\epsilon} = \frac{F/A_0}{\Delta L / L_0}$$

F = force applied, A_0 = original crossection area

ΔL = amount of which the length of the object changes

L_0 = original length

Cantilever

$$\text{strain in the beam} = \frac{a'b' - ab}{ab} = \frac{(R+2)\theta - R\theta}{R\theta} = \frac{z}{R}$$

$$Y = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{\text{tensile stress}}{z/R}$$

Tensile stress on small area $\delta A = \frac{Yz}{R}$

force on area δA = stress × area $= \left(\frac{Yz}{R}\right) \delta A$

$$\text{Moment about the neutral axis} = \frac{Yz}{R} \delta A z = \frac{Yz^2}{R} \delta A$$

Total bending moment for the whole cross section $\frac{\sum Yz^2 \delta A}{R}$ also called geometrical moment of inertia

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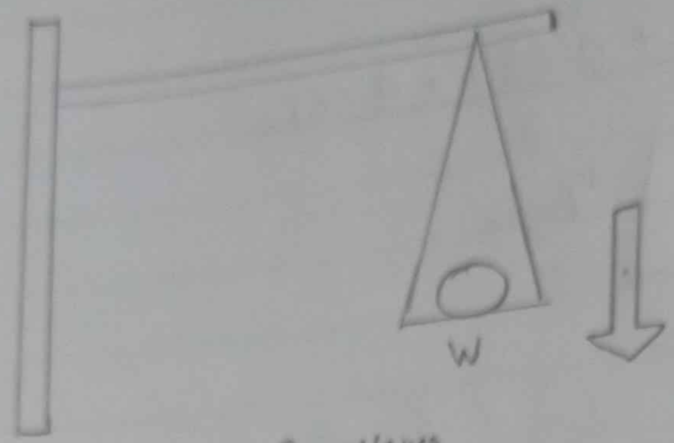


Fig. Cantilever

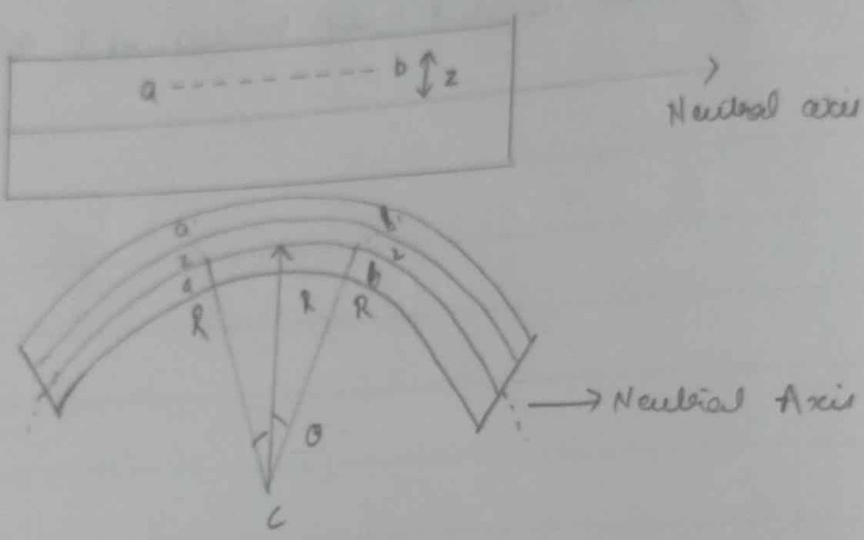
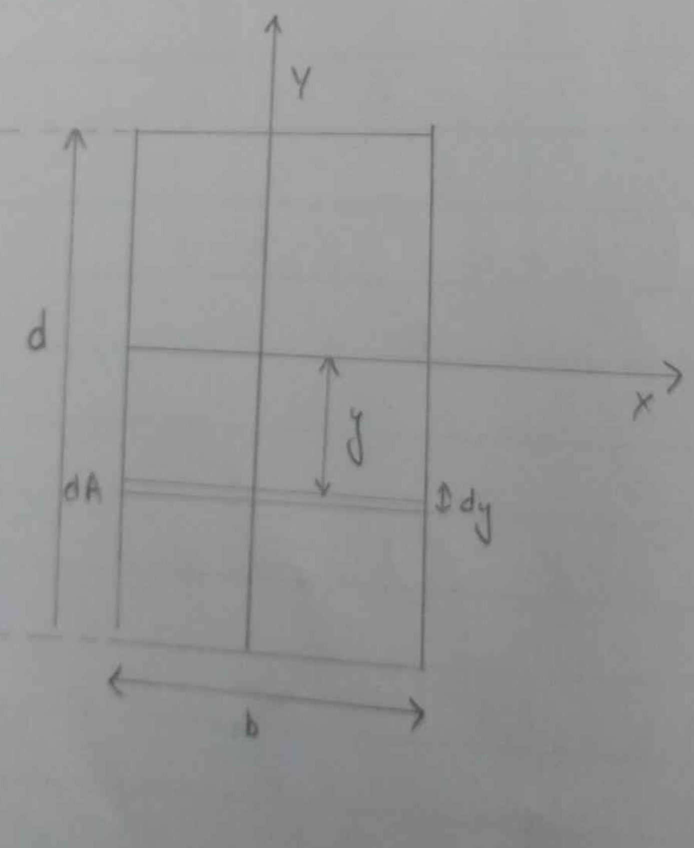


Fig. Bending of beam



Determination of geometrical moment of inertia of rectangular cross section

I (about horizontal middle line) $= b\int_{-\frac{d}{2}}^{\frac{d}{2}} y^2\, dy = \frac{bd^3}{12}$

Bending moment of the beam $M = \frac{YI}{R}$

Bending moment due to load is $W(l-x) = \frac{YI}{R}$

~~Bending~~ Depression $y = d = \frac{Wl^2}{3YI}$

w = weight, I = moment of Inertia, l = length

Double cantilever

The Depression (D) at C is given by $\frac{\left(\frac{W}{2}\right)\left(\frac{l}{2}\right)^2}{3YI} = \frac{Wl^3}{48YI}$

$I = \frac{bd^3}{12}$ $\quad$ b = breadth

d = thickness

Depression of bar $\lambda = \frac{Wl^3}{4Ybd^3}$

Young's modulus of elasticity can be determined by

$Y = \frac{mgl^3}{4bd^3 D}$

$w = mg$

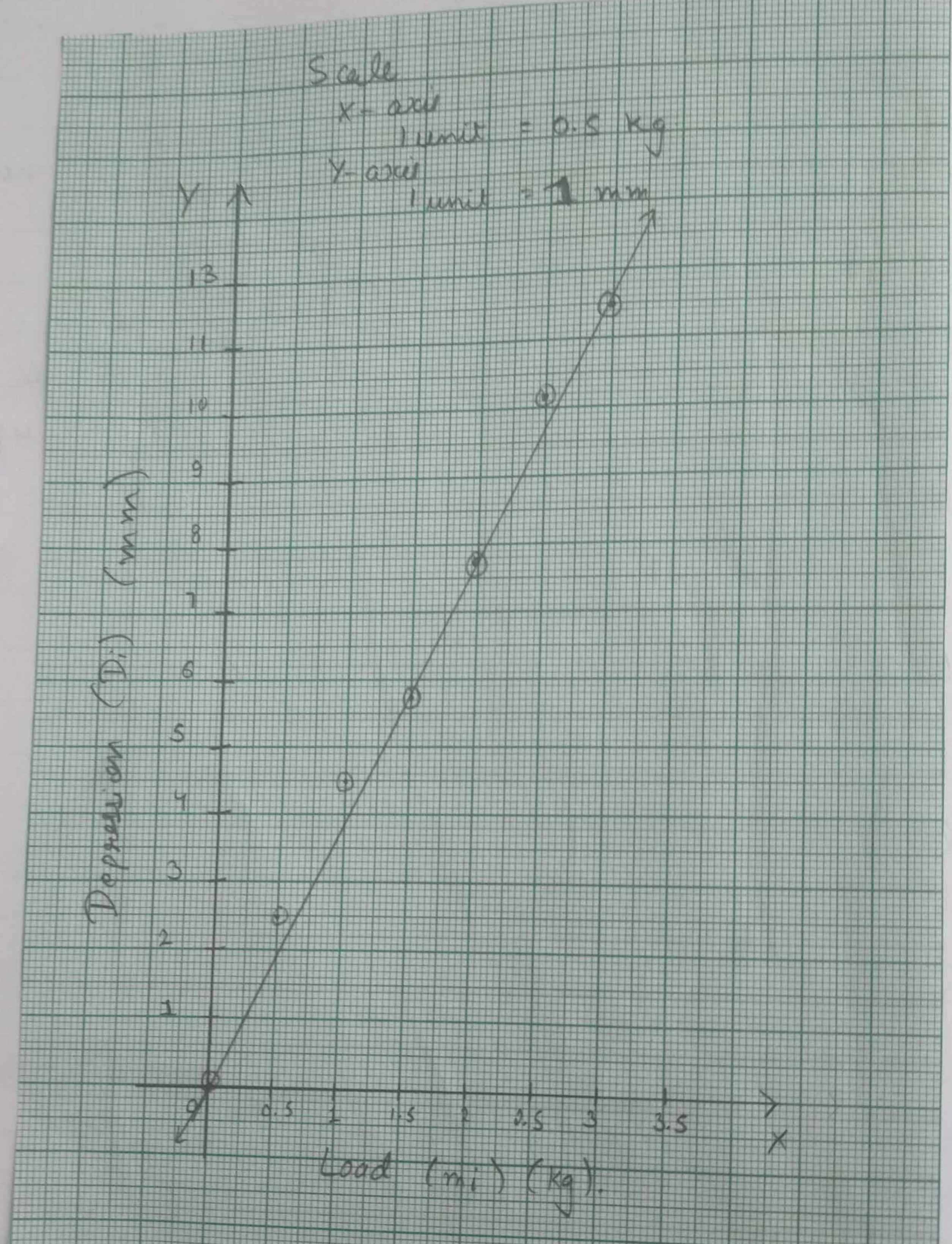
Observation

length (l) = 1 m = 1000 mm

breadth (b) = 6.48 mm

depth (d) = 61.77 mm

Direct calculation of Young's modulus



Scale
X-axis
1 unit = 0.5 kg
Y-axis
1 unit = 1 mm
Y
13
11
10
9
8
7
6
5
4
3
2
1
0
0.5
1
1.5
2
2.5
3
3.5
X
Depression (D_i) (mm)
Load (m_i) (kg).

S.No	Load (m) (kg)	Load Increment M.S.	C.S	T = MS + (C.S x L.C) in mm	Load Increment M.S	C.S	T = M.S + (C.S x L.C) in mm	Mean value of T (mm)	Depression (D) (mm) for 1.5 kg load, $D_n = T_{n+2} - T_{n-1}$	Mean Depression (D) (mm) for 1.5 kg load
1	0.0	2	2	2.02	2	25	2.25.	$T_0 = 2.135$		
2	0.5	4	48	4.48	4	79	4.79	$T_1 = 4.635$		
3	1.0	6	66	6.66	6	97	6.97	$T_2 = 6.815$		5.5525
4	1.5	7	12	7.12	8	19	8.19	$T_3 = 7.655$	$D_1 = 5.52.$	
5	2.0	9	20	9.20	10	56	10.56	$T_4 = 9.88$	$D_2 = 5.245$	
6	2.5	11	66	11.66	12	83	12.83	$T_5 = 12.245$	$D_3 = 5.43$	
7	3	13	65	13.65	13	65	13.65	$T_6 = 13.65$	$D_4 = 5.995$	

Data for depression V/S Load graph

S.No.	Load(m) (kg)	Mean Value of (T) (mm)	Depression (mm) $D_i = T_i' - T_0$
1	0.0	$T_0 = 2.135$	$D_0 = 0$
2	0.5	$T_1 = 4.635$	$D_1 = 2.5$
3	1.0	$T_2 = 6.815$	$D_2 = 4.68$
4	1.5	$T_3 = 7.655$	$D_3 = 5.52$
5	2.0	$T_4 = 9.88$	$D_4 = 7.745$
6	2.5	$T_5 = 12.245$	$D_5 = 10.11$
7	3	$T_6 = 13.65$	$D_6 = 11.515$

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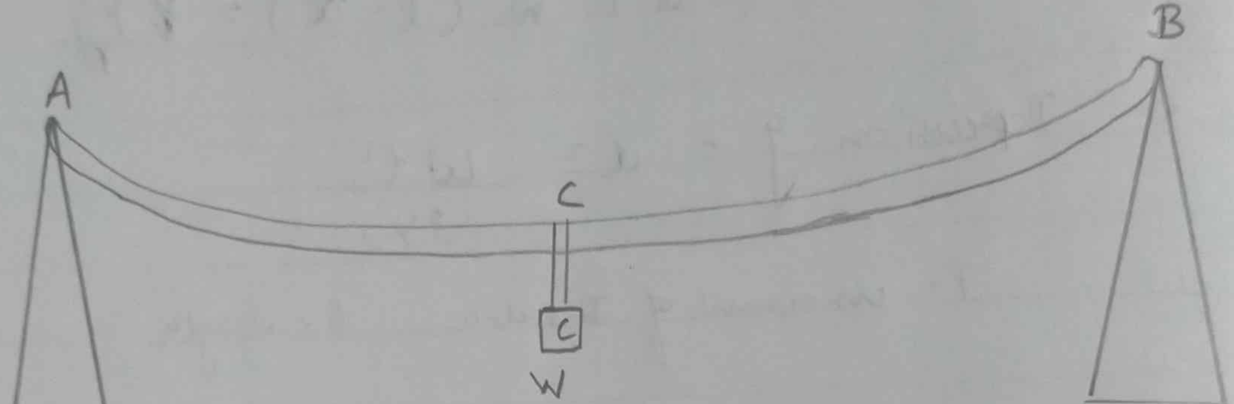

Double Cantilever beam

Calculation

1) Young's modulus (Y) from the mean Depression (D) for a load of 1.5 kg

$$Y = \frac{mgl^3}{4bd^3D}$$

$$= \frac{1.5 \times 9.8 \times (1)^3}{4 \times \frac{6.48}{\cancel{8} \times 10^{-2}} \times (61.72)^3 \times 10^{-3} \times 5.5525 \times 10^{-3}}$$

$$= \frac{14.7}{4 \times 0.00648 \times (0.061)^3 \times 0.0555}$$

$$= \frac{14.7}{3.38 \times 10^{-7}}$$

$$= 4.349 \times 10^7 \ Pa$$

2) Slope of Graph between Depression and Load

$$\text{slope } \mu f = \frac{y_2 - y_1}{x_2 - x_1}$$

$$= \frac{5.5}{2 - 1.5} \times 10^{-3}$$

$$= \frac{5.525}{1.5} \times 10^{-3}$$

$$\mu = 3.68 \times 10^{-3}$$

3) Calculation of Young's Modulus using slope

$$Y = \frac{gl^3}{4bd^3\mu}$$

$$= \frac{9.8 \times 1}{4 \times 0.00648 \times (0.0617)^3 \times 3.68 \times 10^{-3}}$$

$$= \frac{9.8}{2.240 \times 10^{-7}}$$

$$\boxed{Y = 4.375 \times 10^{7} \, Pa}$$

Result

The value of Young's modulus from mean depression is 4.349×10^{7} Pa.
The value of Young's modulus using slope is 4.375×10^{7} Pa.

10/10

Date 23 | 5 | 22

Page No.

Experiment - 5

Aim - To determine the coefficient of static friction between the surfaces of a steel slider and a wooden plane.

Apparatus - Adjustable inclined plane, frictionless pulley, block, standard weights, and inextensible string.

Formula Used :-

$$f_{s,max} = \mu_s N$$

$$f_k = \mu_k N$$

$$N = mg\cos\theta \quad — (1)$$

$$T = Mg$$

$$= mg\sin\theta + \mu_s mg\cos\theta \quad — (2)$$

Or $$\mu_s = \frac{M - m\sin\theta}{m\cos\theta} \quad — (3)$$

$$\mu_s mg\cos\theta_r = mg\sin\theta_r \quad — (4)$$

Or $$\mu_s = \tan\theta_r \quad — (5)$$

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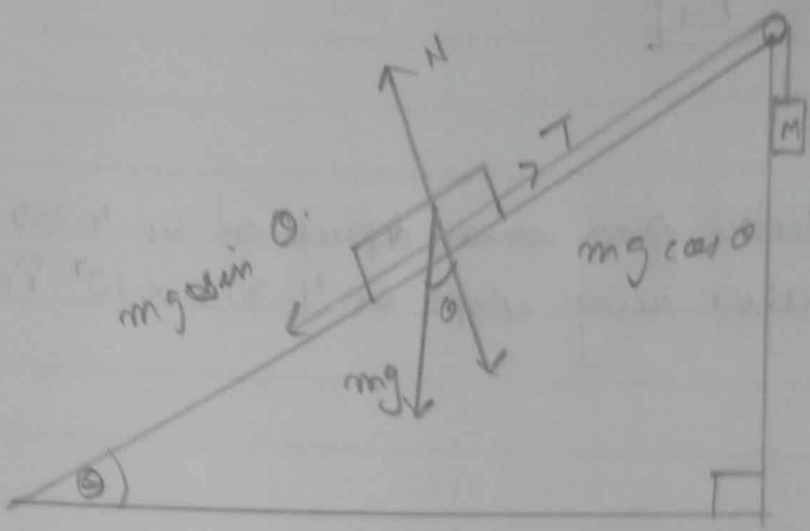

Fig. free body dig.

Expt. No. AA 23/05/22 Page No.

S.NO	θ	m^*(kg)	M^{**}(kg)	$\sin\theta$	$\cos\theta$	μ_s	Mean μ_s
1.	5		31.04	0.017	0.996	0.209	
2.	10		66.04	0.173	0.984	0.461	
3.	15	106.17	76.04	0.258	0.965	0.480	0.445
4.	20		89.04	0.342	0.939	0.535	
5.	25		96.04	0.422	0.906	0.541	

*m is the mass of steel slider.
**M is the mass of the pan including its own mass and the mass of the weights added on it.

S.No.	Angle of Repose, θ_r	μ_s	Mean μ_s
1.	18	0.324	0.349
2.	21	0.383	
3.	22	0.404	
4.	16	0.286	

For Table I

1) $$\mu_{s1} = \frac{M_1 - m\sin\theta_1}{m\cos\theta_1}$$

$$= \frac{31.04 \times 10^{-3} - 0.106(0.087)}{0.106(0.996)}$$

$$= \frac{0.031 - 0.009}{0.105}$$

$$= \frac{0.022}{0.105}$$

$$= 0.209$$

Teacher's Signature

Date

Page No.

2) $\mu_s 2 = \frac{M_2 - m \sin\theta_2}{m \cos\theta_2}$

$$= \frac{0.066 - 0.106(0.173)}{0.106(0.984)}$$

$$= \frac{0.066 - 0.018}{0.104}$$

$$= \frac{0.048}{0.104}$$

$$\approx 0.461$$

3) $\mu_s 3 = \frac{M_3 - m \sin\theta_3}{m \cos\theta_3}$

$$= \frac{0.076 - 1.106 \times (0.258)}{0.106(0.965)}$$

$$= \frac{0.076 - 0.027}{0.102}$$

$$= \frac{0.049}{0.102}$$

$$= 0.480$$

4) $\mu_s 4 = \frac{M_4 - m \sin\theta_4}{m \cos\theta_4}$

$$= \frac{0.089 - 0.106 \times (0.342)}{0.106 \times (0.939)}$$

$$= \frac{0.089 - 0.036}{0.099}$$

$$= \frac{0.053}{0.099} = 0.535$$

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Expt. No. Page No.

5) $\mu_s 5 = \frac{M_5 - m \sin\theta_5}{m \cos\theta_5}$

$= \frac{0.096 - 0.106 \times (0.422)}{0.106 \times (0.906)}$

$= \frac{0.096 - 0.044}{0.096}$

$= \frac{0.052}{0.096}$

$= 0.541$

Result

Thus the mean coefficient of static friction by fixed angle of inclination method is 0.445 and by angle of repose method is 0.349.

9/10

(1) 21/03/22

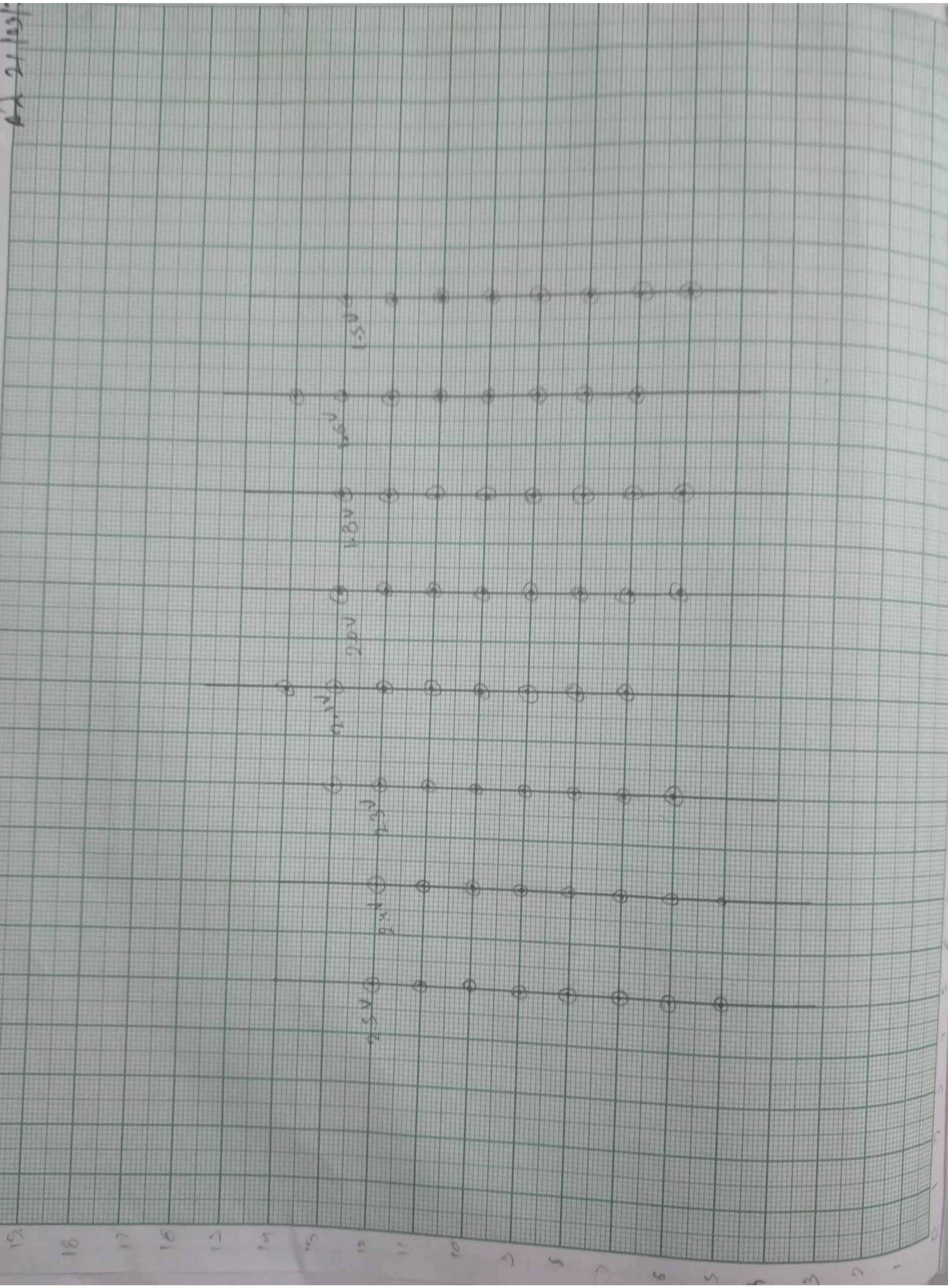
Experiment - 6

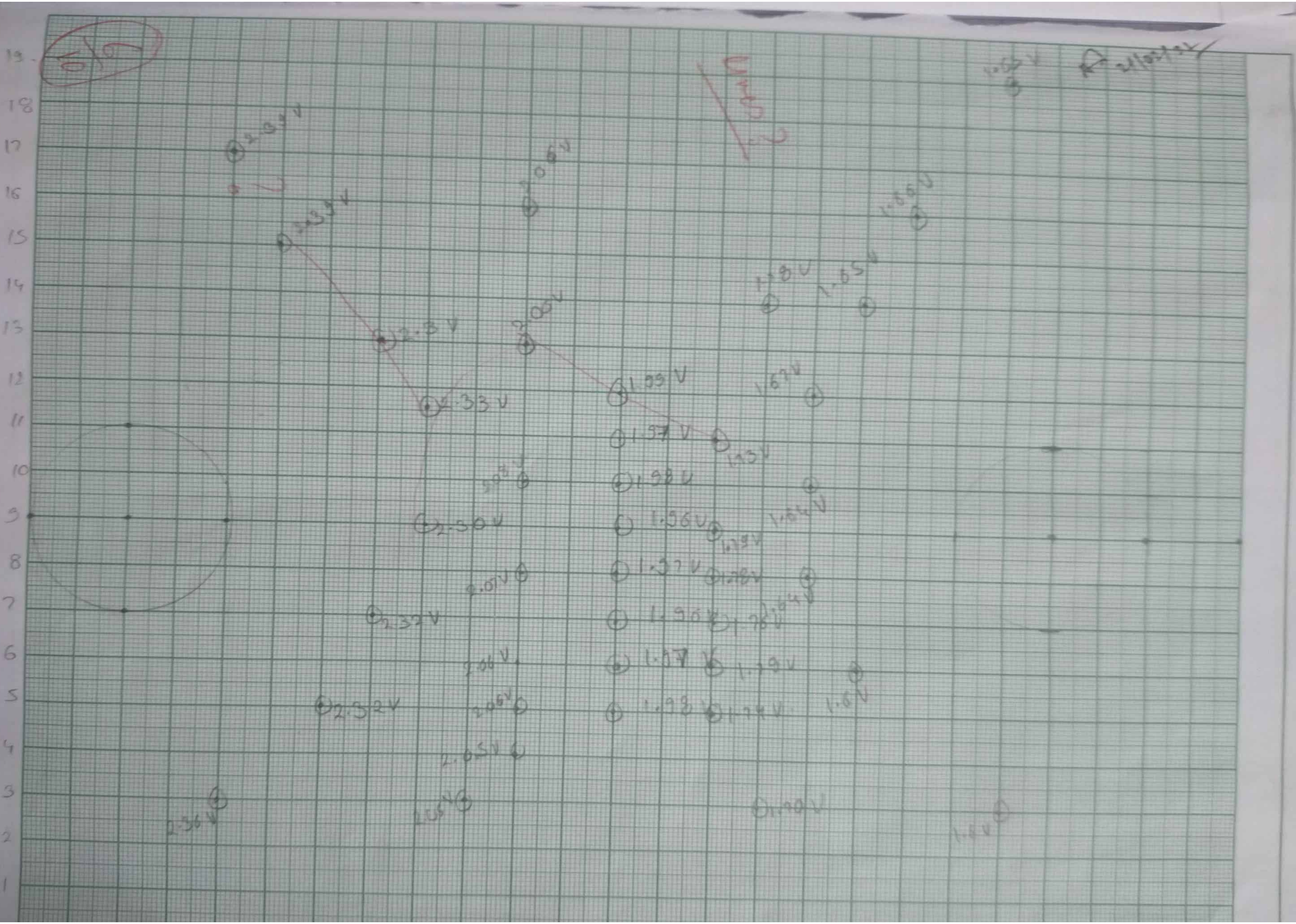
Aim

To draw the equipotential lines of given electrodes.

Apparatus

Power source, Sets of metallic electrodes, Multimeter, Tray and H_2O.


1.5V
1.6V
1.8V
2.0V
2.1V
2.3V
2.4V
2.5V



1.33 V
1.97 V
1.98 V
1.56 V
1.37 V
1.96 V
1.98
2.30 V
2.37 V
2.32 V
1.67 V
1.6 V
1.4 V
1.8 V

Experiment - 7

Aim

Measurement of band gap of a semiconductor using four probe method.

Apparatus

Four probe experimental setup consisting of current source, voltmeter, temperature sensor, oven with controllable temperature, 4 probes for electrical connection, extrinsic semiconductor sample and an insulated sample holder.

Formula used

Conductivity of semiconductor is given by

$$\sigma = e(\mu_n n + \mu_p p) \quad \text{—— (1)}$$

e = electronic charge

μ_n and μ_p mobilities of the electrons and holes

n and p - density of electrons and holes

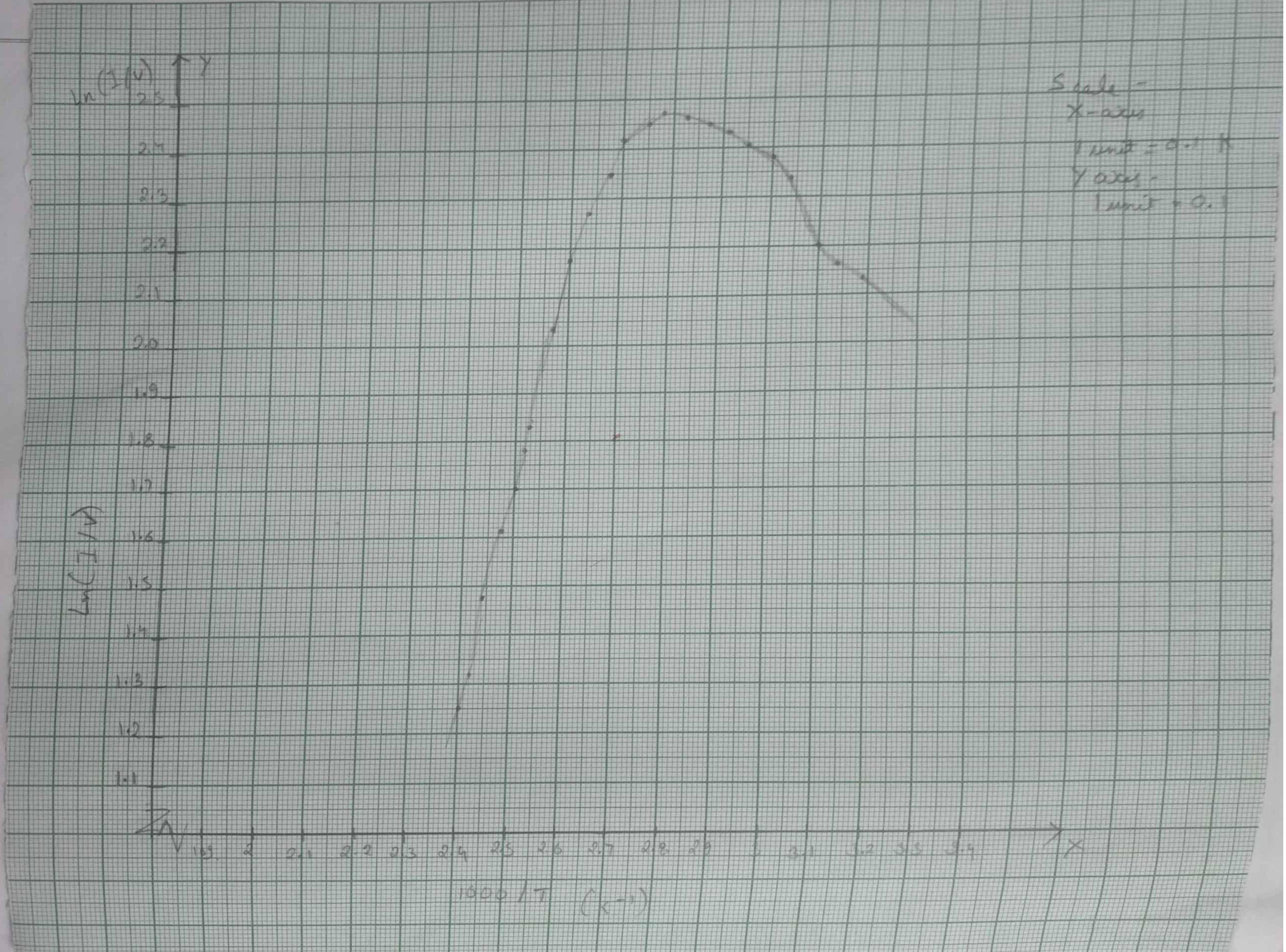
$\mu = V_d / E$.

Conductivity as a function of temperature can be expressed by

$$\sigma(T) = e(\mu_n(T)n(T) + \mu_p(T)p(T)) \quad \text{—— (2)}$$

$$n_i = 2\left(\frac{2\pi k_B T}{h^2}\right)^{3/2}(m_n^* m_p^*)^{3/4}\exp\left(\frac{-E_g}{2K_B T}\right) \quad \text{—— (3)}$$

$$\sigma = \sigma_0 \exp\left(\frac{-E_g}{2K_B T}\right) \quad \text{—— (4)}$$



Scale -
X-axis
1 unit = 0.1 K
Y axis -
1 unit = 0.1
Y
X
1000 / T (K⁻¹)

A/D 28/03/22

* ln(1/V) values were all negative, so modulus of those values was take

S.No.	Temperature	1000/T (K^{-1})	V during increasing T (mV)	V during decreasing T (mV)	Mean V (mV)	|ln(1/V)|
1	40	3.193	66.1	65.1	65.6	2.237
2	45	3.143	67.7.	67.8	67.25	4.25.
3	50	3.104	70.3	70.5	70.4	2.308
4	55	3.047	72.4	73.4	72.9	2.343
5	60	3.001	75.8	75.9	75.85	2.382
6	65	2.957	77.9	78.3	78.1	2.412
7	70	2.914	79.3	80.6	79.95	2.435
8	75	2.872	81.2	82.1	81.65	2.456
9	80	2.831	82.3	83.0	82.65	2.468
10	85	2.799	82.5	82.8	82.65	2.468
11	90	2.753	81.3	81.1	81.2	2.451
12	95	2.716	78.7	77.8	78.25	2.413
13	100	2.679	74.3	73.0	73.65	2.356
14	105	2.644	63.7	67.3	68	2.273
15	110	2.609	62.1	60.6	61.2	2.170
16	115	2.576	54.6	53.5	54.05	2.043
17	120	2.543	48.1	47.8	47.95	1.835
18	125	2.511	41.5.	40.8	41.15	1.777
19	130	3.480	35.4	35.2	35.3	1.617
20	135	2.450	30.5	30.5	30.5	1.471
21	140	2.420	26.3	20 2	26.25	1.321

$$\rho = 2\pi a \frac{V}{I} \quad \text{———} \quad (5)$$

Since $\sigma = 1/\rho$, combining eq 4 and 5

$$\sigma = \sigma_0 \exp\left(\frac{-E_g}{2K_BT}\right) = \frac{1}{2\pi a}\frac{1}{V}$$

$$\ln\sigma_0 - \left(\frac{E_g}{2K_BT}\right) = \ln\left(\frac{1}{2\pi a}\right) + \ln\left(\frac{1}{V}\right)$$

$$\ln\left(\frac{1}{V}\right) = -\left(\frac{E_g}{2K_BT}\right) + \text{const.} = -\left(\frac{E_g}{2000 K_B}\right)\cdot\left(\frac{1000}{T}\right) + \text{const}$$

Thus a plot of $\ln(1/V)$ versus $1000/T$ will be a straight line, with slope (m) given by

$$m = -\left(\frac{E_g}{2000 K_B}\right)$$

The band gap (E_g) of the semiconductor can be calculated from the slope by

$$E_g = -m \cdot 2000 K_B$$

Calculation

1) Slope (m) $= \frac{y_2 - y_1}{x_2 - x_1} = \frac{1.7 - 1.25}{2.5 - 2.4} = \frac{0.45}{0.1} \times \frac{10}{100}$

$$m = 4.5$$

2) $E_g = -m \cdot 2000 K_B$

$$= -4.5\,(2000)\,(1.38 \times 10^{-23})$$

$$E_g = \frac{|-12420 \times 10^{-23} \times 10^4|}{10^4} \text{ scale}$$

$$= |-1.242 \times 10^{-19}| \text{ scale.}$$

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3) $1 eV = 1.6 \times 10^{-19}$,

1.242×10^{-19}

$= \frac{1.242 \times 10^{-19}}{1.6 \times 10^{-19}}$

$= 0.77625\ eV$

10/10

Result

Thus the measurement of band gap of a semiconductor is found using four probe method, that is 0.77625 eV.

Experiment - 8

Aim

Determination of the value of specific charge (e/m) of an electron by Thomson method

Apparatus

Deflection magnetometer, two bar magnets, cathode ray tube with stand arrangement, power supply

Formula used

$$F_e = Ee \quad \text{—— (1)}$$

$$F_{mag} = e|\vec{v} \times \vec{B}| = Bev \sin 90^\circ = Bev \quad \text{—— (2)}$$

$$F_{mag} = Bev = mv^2/r \quad \text{—— (3)}$$

$$e/m = v/Br \quad \text{—— (4)}$$

$$Ee = Bev \quad \text{——} \cancel{(5)}$$

$$v = E/B \quad \text{—— (5)}$$

$$\frac{e}{m} = \frac{E}{B^2 r} \quad \text{—— (6)}$$

$$\tan\theta = OO'/KO \quad \text{—— (7)}$$

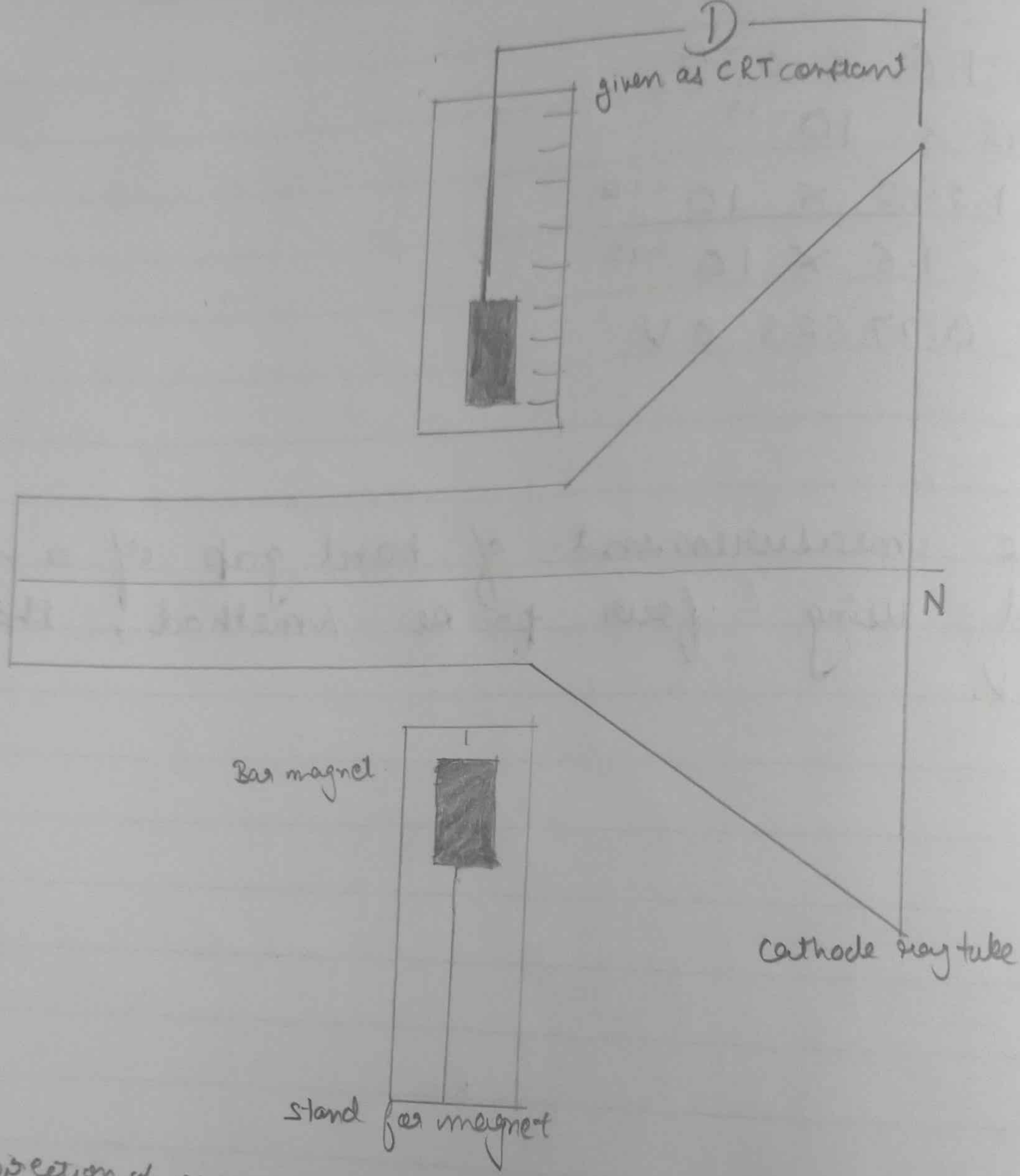
$$\theta = \tan\theta = y/L$$

$$\theta = \tan\theta = \text{arc } GD/r = GM/r,$$

$$\theta = l/r$$

$$l/r = y/L$$

$$r = lL/y$$



Direction of orientation of the cathode ray tube and the magnets.

$$\frac{e}{m} = \frac{Ey}{B^2 l L}$$

$$\frac{e}{m} = \frac{Vy}{B^2 l L d}$$

where d = distance between plates = 1.4 cm
l = length of plates = 3.23 cm
L = distance between screen and plates = 14.5 cm
V = deflection voltage = $(V_1 + V_1')/2$
y = magnitude of deflection in cm

Precautions and sources of error

1) The cathode ray tube should be handeled carefully. There should not be any magnetic substance nearby the place of experiment. Other electronics equipment should be kept away from the setup.

2) Rotate magnet(s) on their axes if spot does not come back to its original positions.

3) The magnets and CRT should be positioned as shown in fig 4 otherwise magnetic field due to the bar magnets will not be in the same location as the electrical deflection plates.

4) The electrical field between plates cannot be uniform due to short distance between them.

5) The given constants of the instrument are generally taken from data provided by the manufacturer, there may be slight variations that can produce error.

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Observation.

Zero error in spot position along the vertical direction (y_0) =

Zero error in voltage reading (V_0) =

Data for deflection voltage and bar magnet position.

Electric field polarity	Deflection y (in cm)	Deflection voltage V (in V)	Average deflection voltage (in V)	Bar magnet position (in cm) and poles facing the CRT magnet	Magnet 2
+	$1 = y_1$	$V_1 = 7.3$		$r_1 = 15(S)$	$r_2 = 10.5(N)$
-		$V_1' = 7.4$	7.35	$r_1' = 10(N)$	$r_2' = 10.4(S)$
+	$0.6 = y_2$	$V_2 = 4.9$		$r_1 = 14.8(S)$	$r_2 = 16.4(N)$
-		$V_2' = 4.8$	4.85	$r_1' = 13.3\ N$	$r_2' = 18(S)$

Calculation of B from the magnetometer reading for $y = y_1$

Bar magnet positions (cm)	Magnetometer deflection (in degree)	Average deflection (in degree)	$B = H \tan\theta$
$r_1 = 15(S)$	$\theta_1 = 68$		0.793×10^{-4}
$r_2 = 10.5\ (N)$	$\theta_2 = 67$	65.5	
$r_3 = 10\ (N)$	$\theta_3 = 65$		
$r_4 = 10.4(S)$	$\theta_4 = 62$		

Calculation of B from the magnetometer reading for $y = y_2$.

Bar magnet position (cm)	Magnetometer deflection (in degree)	Average deflection $\theta = (\theta_1+\theta_2+\theta_3+\theta_4)/4$ (in degree)	$B = H\tan\theta$ (Tesla), $H = 0.37 \times 10^{-4}$ Tesla
$r_1 = 14.8$ (S)	$\theta_1 = 63$		
$r_2 = 16.4$ (N)	$\theta_2 = 64$	45.25	0.3792×10^{-4}
$r_1' = 13.3$ (N)	$\theta_3 = 48$		
$r_2' = 18$ (S)	$\theta_4 = 46$.		

Calculation

1) Standard value e/m

$$= \frac{1.6 \times 10^{-19}}{9.1 \times 10^{-31}}$$

$$= 0.1758 \times 10^{12} \text{ C/kg}$$

2) $$e/m = \frac{Vy}{B^2 l L d}$$

$$e/m = \frac{7.35 \times 1}{(0.793 \times 10^{-4})^2 \times 3.23 \times 14.5 \times 1.4}$$

$$e/m = \frac{7.35}{0.6288 \times 10^{-8} \times 65.569}$$

$$\boxed{e/m = 0.17826 \times 10^{12}}$$?

3) % error $\Rightarrow \dfrac{\text{Standard value} - \text{Calculated value}}{\text{Standard value}} \times 100$

$$= \frac{(0.1758 - 0.17826)\cancel{10^{12}}}{0.1758 \times \cancel{10^{12}}} \times 100 = 0.01365 \times 100$$

$$\boxed{\%\text{error} = 1.365\%}$$

10/10

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Result

1) Calculated value of e/m for electrons is 0.17826×10^{12} C/kg

2) standard value of e/m for electrons is 0.1758×10^{12} C/kg

3) Calculated percentage error is 1.365%

Experiment - 9

Aim

To study conservation of momentum and kinetic energy during collisions.

Apparatus:

Linear air track, triangular gliders, air blower, digital data logger, gates with IR sensor and LED, accessories that can be plugged into gliders for different measurements, weights, balance

Formula used

$$m_1\vec{u_1} + m_2\vec{u_2} = m_1\vec{v_1} + m_2\vec{v_2}$$
$$m_1\vec{u_1} + m_2\vec{u_2} = (m_1+m_2)\vec{v}_{1,2}$$

Kinetic energy in elastic collision : $\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}mv_2^2$

Kinetic energy inelastic collision : $\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 \neq \frac{1}{2}(m_1+m_2)v_{12}^2$

where - m_i = mass
$\vec{u_i}$ = initial velocity (before collision)
$\vec{v_i}$ = final velocity (after collision)

5) $\left|\frac{(m_1u_1+m_2u_2) - (m_1\vec{v_1} + m_2v_2)}{m_1u_1+m_2u_2}\right| \times 100$ {% change in momentum for elastic collision}

6) $\left|\frac{(m_1u_1+m_2u_2) - ((m_1+m_2)v_{12})}{m_1u_1+m_2u_2}\right| \times 100$ {for inelastic collision}

7) $\frac{\left(\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_1v_2^2\right) - \left(\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2\right)}{\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_1v_2^2} \times 100$ {% change in K.E. for elastic collision}

8) $\left|\frac{\left(\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_1v_2^2\right) - \left(\frac{1}{2}(m_1+m_2)v_{12}^2\right)}{\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_1u_2^2}\right| \times 100$ for inelastic collision.

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11/04/22

Observations:-

Data for elastic collision

Case	Mass m_1 in g	Mass m_2 in g	Speeds from data logger in cm/s				Velocities * before collisions in cm/s		Velocities * after collision in cm/s		% change in momentum	% change in Kinetic energy
			"initial 1"	"final 1"	"initial 2"	"final 2"	$\vec{u_1}$	$\vec{u_2}$	$\vec{v_1}$	$\vec{v_2}$	~~92.7~~	
1.	226.9	224.5	0.3906	0.8333	0.0367	0.0031	0.3905	0	0	0.0367	92.7	99.12
2.	329.6	224.5	0.6711	0.1828	0.7843	0.2099	0.6711	-0.7843	-0.1823	-0.2099	38.6	92.70
3.	226.9	224.5	0.4751	0.4464	0.7326	0.5420	0.4751	-0.7326	-0.4464	-0.5420	2.18	35.25

Mean value of % change in momentum = 44.4%

Mean value of % change in Kinetic energy = 75.69%

Expt. No. ______________ Page No. ______________

Data for inelastic collision.

Case	Mass m_1 in g	Mass m_2 in g	Speeds from data logger in cm/s				Velocities * before collision in cm/s		Velocity * after collision in cm/s	% change in momentum	% change in kinetic energy
			"initial 1"	"final 1"	"initial 2"	"final 2"	$\vec{u_1}$	$\vec{u_2}$	$\vec{v_{1,2}}$		
1.	218.1	220.2	0.2451	0.2427	0.1936	0.8199	0.2451	0	0.1936	58.74	25.37
2.	318.6	220.2	0.2125	0.2062	0.5470	0.1577	0.2125	0	0.5470	33.5	10.20
3.	218.1	220.2	0.1280	0.0813	0.6734	0.5873	0.1280	-0.6734	0.5873	46.0	46.17

Mean value of % change in momentum = 46.08%

Mean value of % change in kinetic energy = 27.24%

Calculation

For % change in momentum : for elastic collision

$$\left|\frac{(m_1u_1 + m_2u_2) - (m_1v_1 + m_2v_2)}{m_1u_1 + m_2u_2}\right| \times 100$$

Case 1

$$100 \times \left[\frac{((226.9)(0.3906) + 0) - ((226.9)(0) + (224.5)(0.0367))}{(226.9)(0.3906)}\right]$$

$= 92.7\%$

Case 2

$$\frac{((327.6)(0.6711) + (224.5)(-0.7843)) - ((327.6)(-0.1828) + (224.5)(-0.2099))}{(327.6)(0.6711) + (224.5)(-0.7843)}$$

$= 38.6\%$

Case 3

$$\frac{((226.9)(0.4751) + (224.5)(-0.7326) - ((226.9)(-0.4464) + (224.5)(-0.5420))}{(226.9)(0.4751) + (224.5)(-0.7326)} \times 100$$

$= 2.18\ \%$

for inelastic collision

$$\left| \frac{(m_1u_1 + m_2u_2) - ((m_1+m_2)v_{12}}{m_1u_1 + m_2v_2} \right| \times 100$$

Case 1.

$$\left| \frac{((218.1)(0.2451)+0) - ((218.1+220.2)(0.1936))}{(218.1)(0.2451)} \right| \times 100$$

$= 58.74\%$

Case 2

$$\left| \frac{((318.6)(0.2125)+0)((318.6 + 220.2)(0.5470))}{(318.6)(0.2125)} \right| \times 100$$

$= 33.5\ \%$

Case 3

$$\left| \frac{((218.1(0.1280) + (220.2)(-0.6734)) - ((218.1 + 220.2)(0.5873))}{(218.1)(0.1280) + (220.2)(-0.0734)} \right| \times 100$$

$= 46.0\ \%$

for % change in K.E for elastic collision

$$\left| \frac{(\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_1v_2^2) - (\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2)}{\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2} \right| \times 100$$

Case 1

$$\frac{(\frac{1}{2}(226.9)(0.3906)^2 + \frac{1}{2}(224.5)(0)) - (\frac{1}{2}(226.9)(0) + \frac{1}{2}(224.5)(0.0367)^2}{\frac{1}{2}(226.9)(0.3906)^2} \times 100$$

$= 99.12\ \%$

Expt. No. ______ Page No. ______

Case 2

$$100 \times \frac{\left((327.6)(0.6711)^2 + (224.5)(0.7843)^2\right) - \left((327.6)(-0.1828)^2 + (224.5)(-0.2055)^2\right)}{(327.6)(0.6711)^2 + (224.5)(-0.7843)^2}$$

$= 92.04\,\%$

Case 3

$$100 \times \frac{\left((226.9)(0.4751)^2 + (224.5)(-0.7326)^2\right) - \left((226.9)(-0.4464)^2 + (224.5)(-0.5420)^2\right)}{(226.9)(0.4751)^2 + (224.5)(-0.7326)^2}$$

$= 35.257\%$

for inelastic collision.

$$\left| \frac{\left(\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_1 u_2^2\right) - \left(\frac{1}{2}(m_1 + m_2) v_{12}^2\right)}{\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_1 u_2^2} \right| \times 100$$

Case 1

$$\left| \frac{(218.1)(0.2451)^2 - \left((218.1 + 220.2)(0.1936)^2\right)}{(218.1)(0.2451)^2} \right| \times 100$$

$= 25.327\%$

Case 2

$$\left| \frac{(318.6)(0.2125)^2 - \left((318.6 + 220.2)(0.5470)^2\right)}{(318.6)(0.2125)^2} \right| \times 100$$

$= 10.20\,\%$

Case 3

$$100 \times \frac{\left((218.1)(0.1280)^2 + (220.2)(-0.6734)^2\right) - \left((218.7) + 220.2)(0.5873)^2\right)}{(218.1)(0.1280)^2 + (280.2)(0.6734)^2}$$

$= 46.17\%$

Result

Mean value of % change in momentum during elastic collision = 44.4%

Mean value of % change in Kinetic energy during elastic collision = 73.69%

Mean value of % change in momentum during inelastic collision = 46.08%

Mean value of % change in Kinetic energy during inelastic collision = 27.74%

Discussion

From above experiment, we observe that the percentage change is really large, this could be due to manual force applied on the bodies.

9/10

Experiment - 10

Aim -
To determine the normal mode frequencies of a coupled oscillator and verify beat frequency is a linear combination of the normal mode frequencies.

Apparatus -
1) Coupled pendulum
2) Two springs
3) Hanger
4) Weights 50 gms each
5) Stop watch

Formula Used
m - mass
l - length of rod.

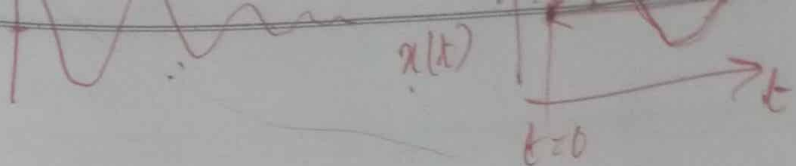
$$m\ddot{x} = -mg\frac{x}{l} - k(x-y)$$

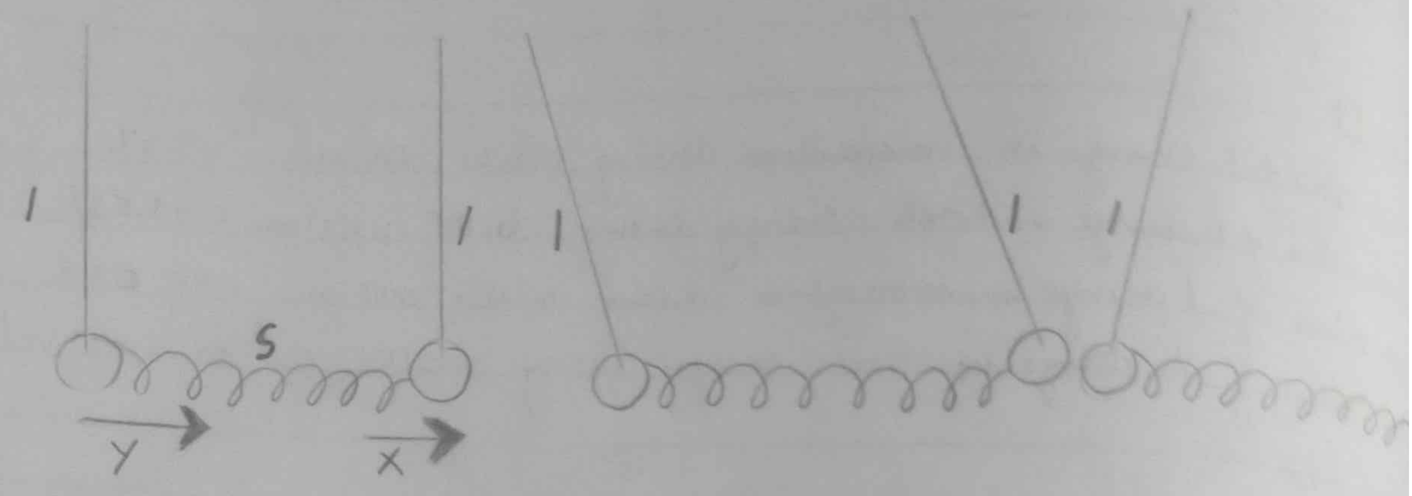
$$m\ddot{y} = -mg\frac{y}{l} + k(x-y)$$

$$\omega_0^2 = \frac{g}{l},$$ where ω_0 is natural vibration frequency.

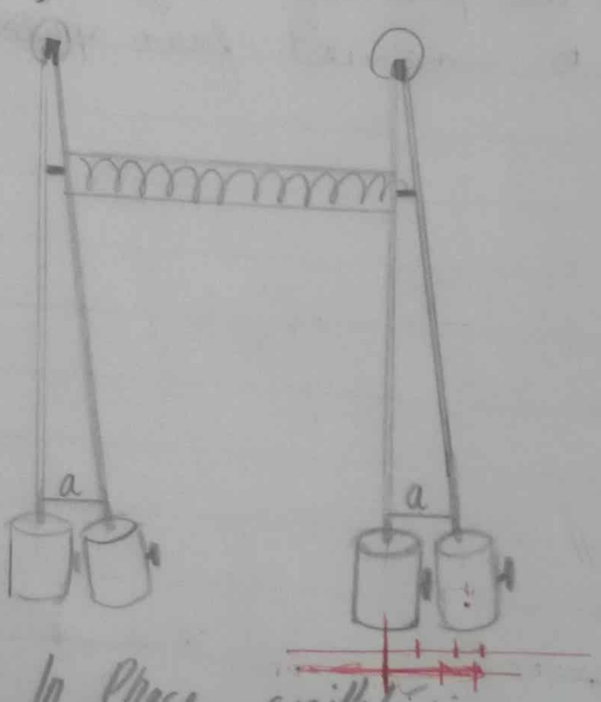
$$\ddot{x} + \omega_0^2 x = -\frac{k}{m}(x-y)$$

$$\ddot{y} + \omega_0^2 y = -\frac{k}{m}(y-x).$$

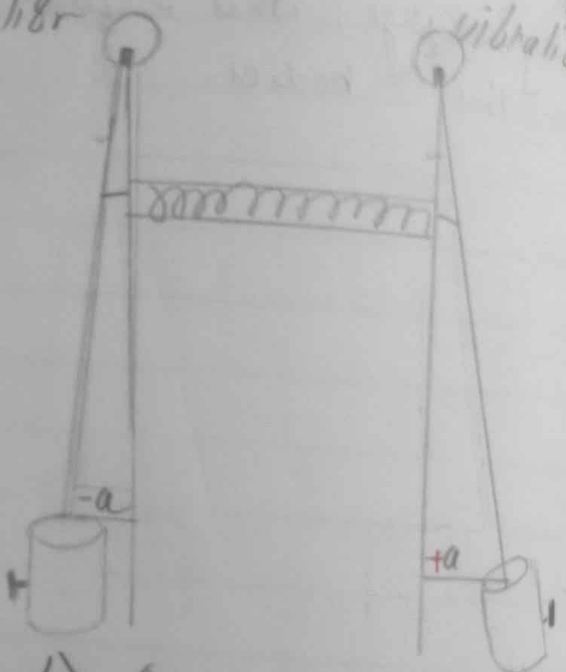




a) coupled Pendulum b) The in phase mode of vibration c) The out... mode of vibration



a) In Phase oscillation



b) Out of Phase oscillation

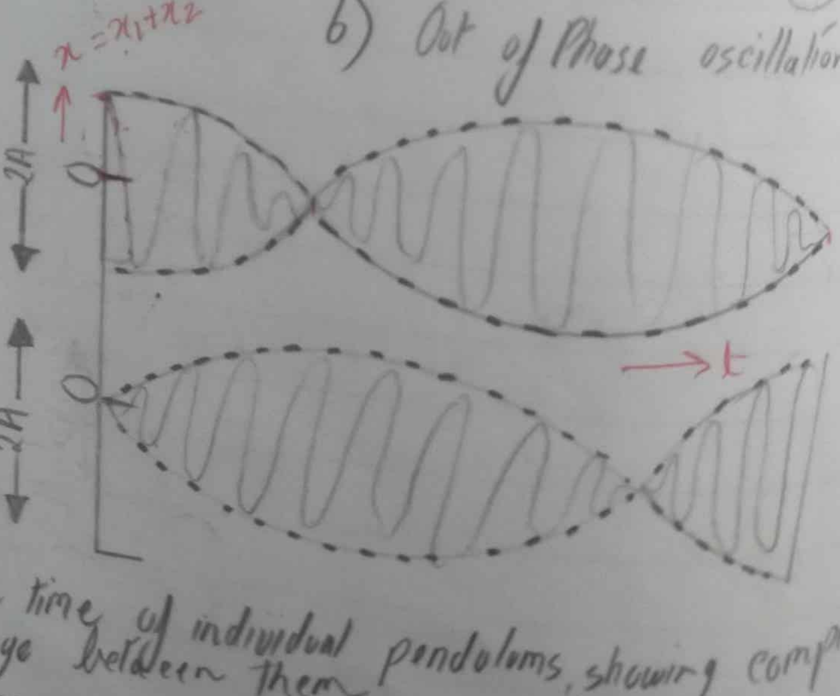


Fig. Behaviour with time of individual pendulums, showing complete energy exchange between them

$$X = x+y$$
$$Y = x-y$$
$$\ddot{x} + \ddot{y} + \omega_0^2(x+y) = 0$$
$$\Rightarrow \ddot{X} + \omega_0^2 X = 0$$
$$\ddot{Y} + \left(\omega_0^2 + \frac{2k}{m}\right) Y = 0$$

$$\ddot{X} + \omega_0^2 X = 0.$$
$$\ddot{Y} + \left(\omega_0^2 + \frac{2k}{m}\right) Y = 0$$

$$X = x+y = X_0 \cos(\omega_1 t + \phi_1)$$

$$Y = x-y = Y_0 \cos(\omega_2 t + \phi_2)$$

where X_0 and Y_0 are normal mode amplitudes,

and $\omega_1^2 = \frac{g}{l}$ and $\omega_2^2 = \frac{g}{l} + \frac{2k}{m}$

$$x = a\cos(\omega_1 t) + a\cos(\omega_2 t)$$
$$= 2a\cos\frac{(\omega_2-\omega_1)t}{2}\cos\frac{(\omega_1+\omega_2)t}{2}.$$

and that left hand pendulum is given by

$$y = a\cos(\omega_1 t) - a\cos(\omega_2 t)$$
$$= 2a\sin\frac{(\omega_2-\omega_1)t}{2}\sin\frac{(\omega_1+\omega_2)t}{2}.$$

$$\omega_1 = \sqrt{\frac{g}{l}}$$

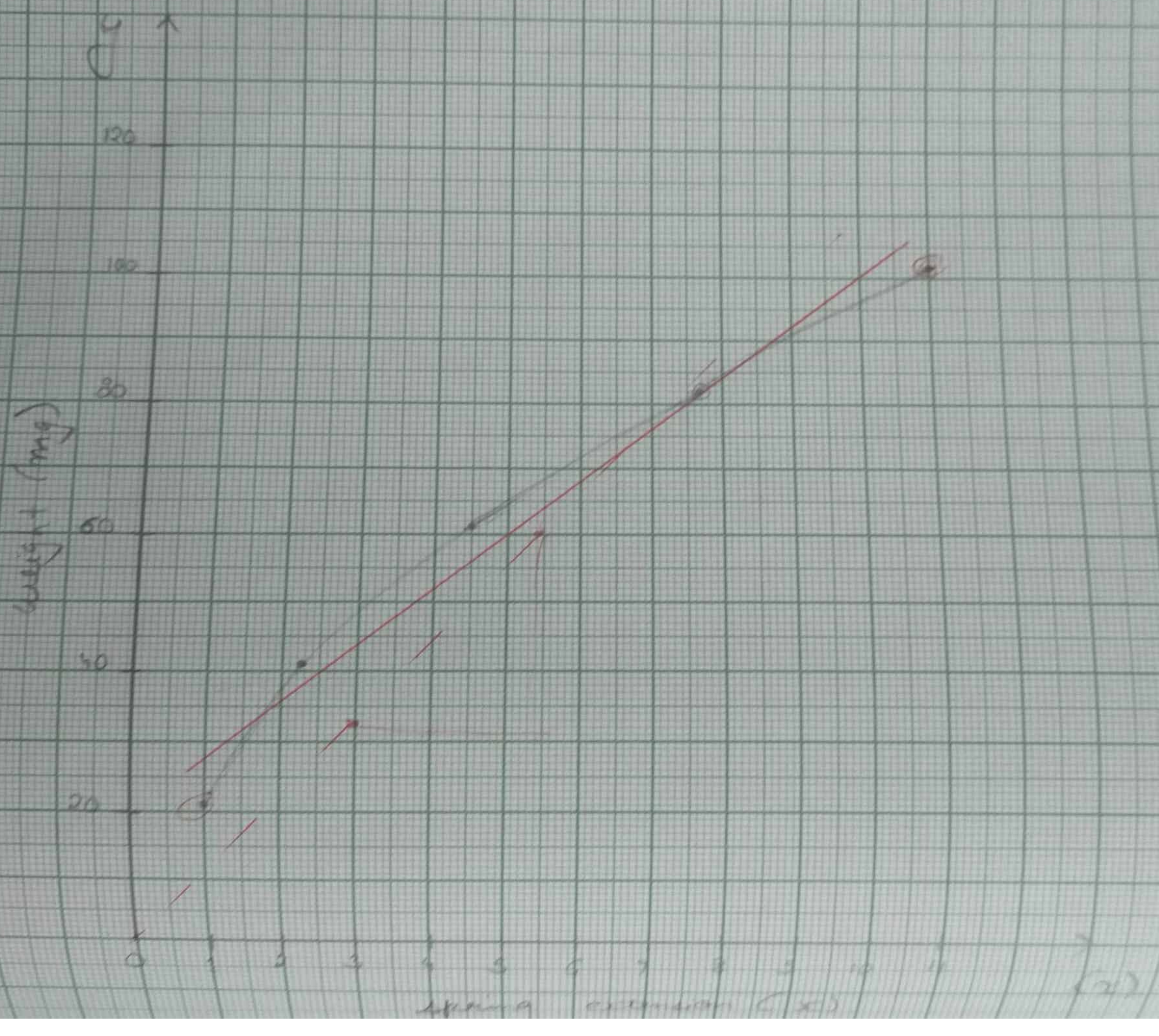
$$\omega_2 = \sqrt{\omega_1^2 + \frac{2kd^2}{ml^2}}$$

where $l = 72.5$ cm

$m = 283.2$ gm

$d = 36.25$ gm.

Scale
x - axis
1 unit = 1 cm
Y - axis
1 unit = 10 mg



$$\omega_c = \frac{\omega_1 + \omega_2}{2}$$

$$\omega_B = \frac{\omega_2 - \omega_1}{2}$$

Observation

Spring constant measurement:-

length of the unextended spring (x_0) = 14.5

S.No	Weight (mg)	Spring length (x_1)	Spring extension $x = x_1 - x_0$
1	20.3	15.5	1.0
2	40.7	16.6	2.3
3	61.1	19	4.5
4	81.5	22.2	7.7
5	101.9	25.5	11
6			

Time period measurement.

Time period	Angular frequency
T_1 - 1.675	ω_1 = 3.74
T_2 - 1.576	ω_2 = 3.984
T_c - 1.67	ω_c = 3.764
T_B = 35.226	ω_B = 0.1782.

Calculation

1) For spring constant (K)

slope (m) = $K = \dfrac{y_2 - y_1}{x_2 - x_1}$

$= \dfrac{95 - 70}{10 - 6} = \dfrac{25}{4}$

$= 6.25$

2) Theoretical normal mode frequencies

$\omega_1 = \sqrt{\dfrac{g}{l}} = \sqrt{\dfrac{98}{72.5}} = \sqrt{0.137} = 0.3701$

$\omega_2 = \sqrt{(\omega_1)^2 + \dfrac{2kd^2}{ml^2}} = \sqrt{0.137 + \dfrac{2(6.25)(36.25)^2}{783.2\ (72.5)^2}}$

$= \sqrt{0.137 + \dfrac{16425.78}{4116.695}}$

$= \sqrt{0.14099}$

$\omega_2 = 0.37548$

3) calculated carrier and beat frequencies from the experimental normal mode frequencies

$\omega_C = \dfrac{\omega_1 + \omega_2}{2} = \dfrac{3.74 + 3.984}{2} = 2.361$

$\omega_B = \dfrac{\omega_2 - \omega_1}{2} = \dfrac{3.984 - 3.74}{2} = 0.122$

4) Calculated carrier and beat frequencies from the theoretical normal mode frequencies

$$\omega_C = \frac{\omega_1 + \omega_2}{2} = \frac{0.3701 + 0.37548}{2} = 0.3727$$

$$\omega_B = \frac{\omega_2 - \omega_1}{2} = \frac{0.37548 - 0.3701}{2} = 0.00269$$

Result

1) Spring constant $K = 6.25$
2) Theoretical normal mode frequencies $\omega_1 = 0.3701$
$\omega_2 = 0.37548$
3) Experimental normal mode frequencies $\omega_1 = 3.74$
$\omega_2 = 3.984$
4) Experimental carrier and beat frequencies $\omega_C = 3.764$
$\omega_B = 0.1782$
5) Calculated carrier and beat frequencies from experimental normal mode frequencies $\omega_C = 3.861$ $\omega_B = 0.122$
6) Calculated carrier and beat frequencies from the theoretical normal mode frequencies
$\omega_C = 0.3727.$
$\omega_B = 0.00269$

Precautions

1) The angular amplitude should be kept small.
2) While using the spring, keep its length natural i.e neither extended nor compressed.
3) The oscillations should be in plane.

7/10

Teacher's Signature