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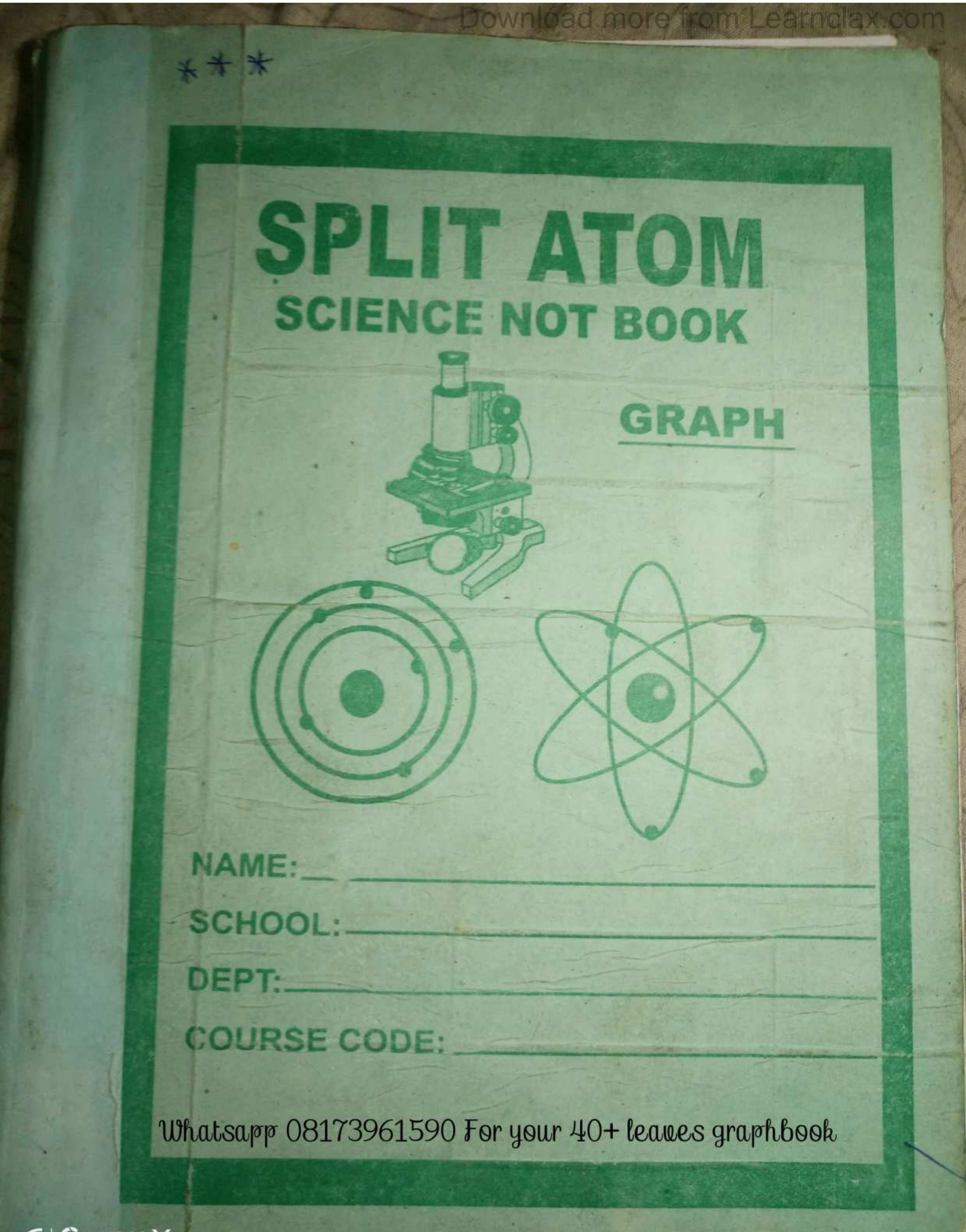
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Experiment 01: DETERMINATION OF ACCELERATION DUE TO GRAVITY USING A KATER'S PENDULUM

Aim: To Determine The Acceleration due to Gravity (g)

Apparatus:
* A kater's Pendulum
* A Stopwatch
* A meter rule
* A Knife edge

Procedure

i. I Suspended the pendulum vertically from its knife edge ($K1$) at an arbitrary position of the knife edge.

ii. I displaced the pendulum (Sideways), released it, and timed it for 50 oscillations. I Calculated the period (T) of the Oscillations thereafter

iii. I repeated the procedure in (ii) above, four more times, attained Similar values of T and then Calculated my average period (T_1)

iv. Again I Suspended the pendulum vertically but this time, from the other knife edge (K_2).

v. I displaced the pendulum, released it and timed for 50 oscillations adjusting the knife edge until I attained a position of the knife edge that gave a reasonably Close period (T_2) to the previous period (T_1)

vi. With this position of K_2 I initiated and timed 50 oscillations of the pendulum four more times, Solved for the period in each Case and Calculated my average T_2.

vii. I balanced the pendulum at K_2 again and made further adjustments to the already attained period due to movement of K_2.

viii. In other to attain my distance D_1 and D_2, I balanced the pendulum on a knife edge, noted the Centre of mass and took measurements of D_1 and D_2 with a metre rule.

My table of values appeared thus:

For K_2

	t(s)	T_2 (s)
1	94.88	1.898
2	94.82	1.896
3	94.52	1.890
4	94.37	1.887
5	94.84	1.897

Mean T_2 = 1.894 d_2 = 69.1 cm

For K_1

	t(s)	T_1 (s)
1	96.31	1.926
2	96.70	1.934
3	96.26	1.925
4	96.35	1.927
5	96.40	1.928

Mean T_1 = 1.928 d_1 = 22.9

No. of Oscillation = 50

from $\frac{4\pi^2}{g} = \frac{T_1^2 D_1 - T_2^2 D_2}{D_1^2 - D_2^2}$

deducing gravity (g)

$$g = \frac{(D_1^2 - D_2^2) 4\pi^2}{\cancel{4\pi^2}(T_1^2 D_1 - T_2^2 D_2)}$$

where $T_1 = 1.928\,s$

$T_2 = 1.894\,s$

$D_1 = 22.9\,cm$

$D_2 = 69.1\,cm$

$$g = \frac{(39.478)(4774.81 - 524.41)}{(3.7171)(69.1) - (3.587)(22.9)}$$

$$g = \frac{(39.478)(4250.4)}{(256.85) - (82.1423)}$$

$$g = \frac{167797.29}{174.7077}$$

$$g = 960.445\ cm/s^2 = \underline{\underline{9.6\,m/s^2}}$$

Other Sources of Errors

i. Worn-out / Uneven knife edges.
ii. Friction between the knife edges and the rigid support during oscillation.

Precautions

i. I ensured that the amplitude of vibration (oscillation) is small so that the motion of the pendulum satisfies the conditions of a S.H.M
ii. While timing the oscillations, I started my stopwatch after the pendulum had made a few oscillations (and was at the far end of the oscillation arc) to avoid any irregularity of motion.
iii. I ensured that the two knife edges are parallel to each other when placed — on either edges — on the rigid support.

Conclusion

Within the limits of my (experimental) errors, I have determined — using a Kater's pendulum — the value of the acceleration due to gravity (g) as 9.6 ±

Experiment 02 : FREE OSCILLATION OF A DAMPED MECHANICAL SYSTEM.

Aim : * To Investigate the effect of amount of damping on the time Constant of decay of Oscillation.
* To Investigate the effect of damping on the logarithmic decrement of amplitude of Oscillation.

Apparatus : * Ruler
* Cork (with two diametric slits Intercepting each other at right angles)
* Tuning mass — with Screws
* Small Cardboard (10cm x 5cm) — with an attached pin projecting Centrally from on edge.
* Base plate (with blade Securing Screws)
* G-clamp
* Retort Stand
* Oscillator blade * Stop Watch

Procedure — Part 1

1. Setting up the apparatus :
i. I clamped the base plate to the edge of a bench and clamped the end of the oscillator blade vertically to the base plate by means of two fixing Screws.
ii. I attached the tuning mass to the blade by feeding the blade between the disc and Securing by means of Screws.
2. I pulled the top of the blade on one Side, released it, timed (with a stopwatch) and Caculated the period for 50 oscillations while measuring and taking note of distance of the tuning mass

from above the base plate.

3. I repeated procedure (2) for five more positions of the tuning mass with one of the positions being 'near the middle'
I tabulated my readings/results and my table appeared thus :-

Distance of tuning mass (cm)	(t) time (s)	(T) Period (s)	(f) Frequency (Hz)
18.2	22.72	0.4544	
19.5	25.87	0.5174	
22.5	32.77	0.6554	
23.7	36.67	0.7334	
26.2	46.10	0.922	
27.5	51.46	1.0292	

No. of Oscillation = 50

Part 2

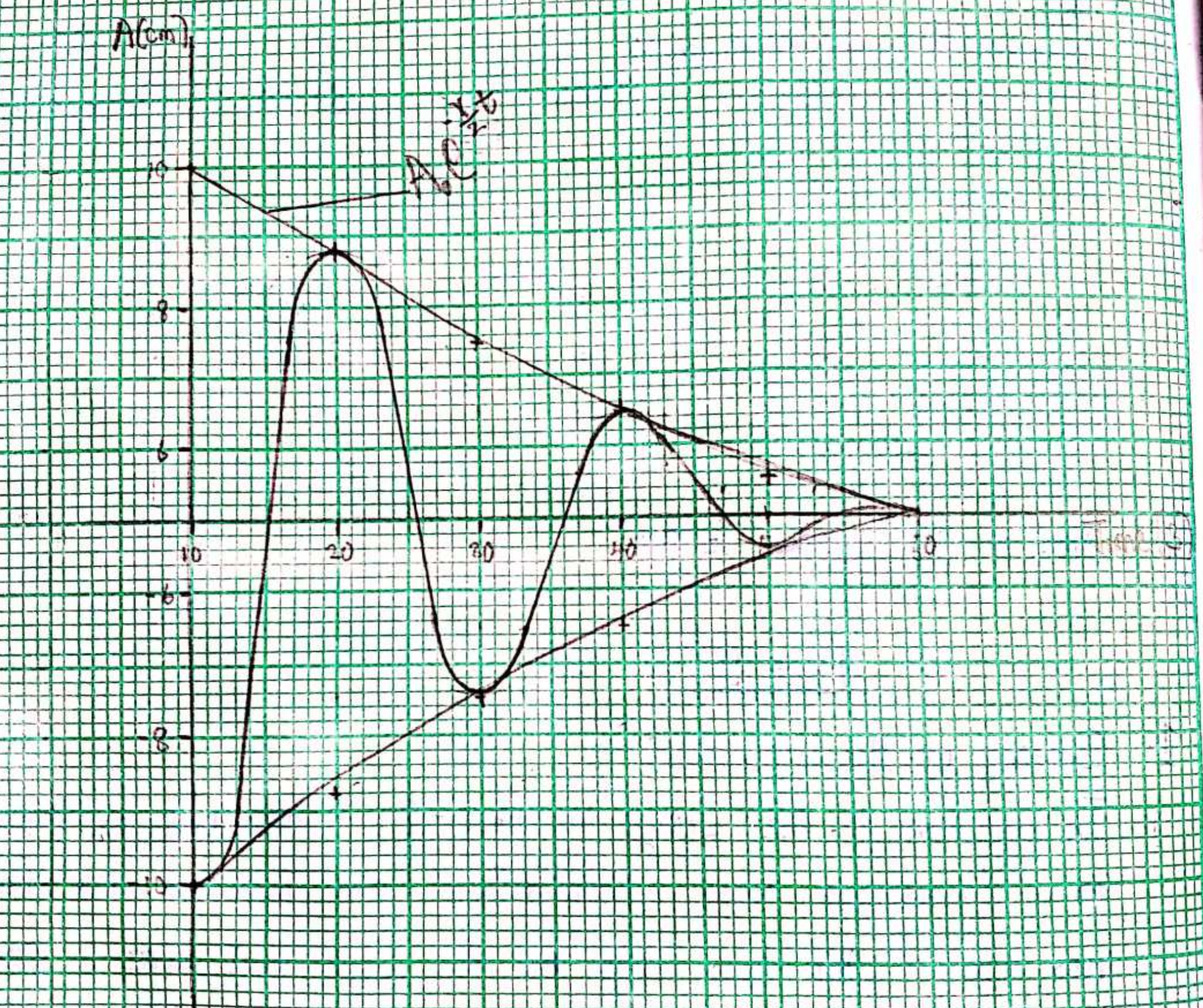
1. Setting up the apparatus :
i. In addition to the Setup in Part-1, I attached an Ordinary Pin to a Cardboard Paper (10cm x 5cm) and Inserted the Cardboard into one of the two Slits on the Cork that was in parallel to the plane of Oscillation (as this would give minimum damping).
ii. I Clamped a ruler horizontally behind the pointer — the ordinary pin attached to the Cardboard — and marked the rest position (Y_1) of the pin on the ruler so that amplitude can be observed as deviation from this point.

2. I pulled the blade on one side, released it and noted the Peak positions $Y_1, Y_2, \ldots, Y_5$ of the pointer at time $t_1, t_2, \ldots, t_5$

Scale: 2cm to 2units on y-axis
: 2cm to 10units on x-axis

Origin $(x,y) = (10,6)$

Decay Curve for Minimum Damping



Minimum

(at an Interval of 10seconds).

3. I Subtracted (mentally) the value of the initial position (Y_0) from each of the positions $Y_1, Y_2, ..., Y_5$ to get my initial, through to the 5th amplitude.

I tabulated my readings thus :-

For minimum damping

Time (s)	Printer Position (cm)	Amplitude (Cm)	% Amplitude $\left(\frac{Y_2 - Y_0}{Y_1 - Y_0} \times 100\%\right)$
10	74.0	10	100
20	72.8	8.8	88
30	71.5	7.5	85
40	70.5	6.5	87
50	69.5	5.5	85
60	69.0	5	90

$Y_0 = 64cm$

4. I modified the position of the Cardboard i.e I inserted it in the Second Slit, perpendicular to the plane of Oscillation for maximum damping

5. With this new position of the Cardboard, I repeated procedure (2) and (3)

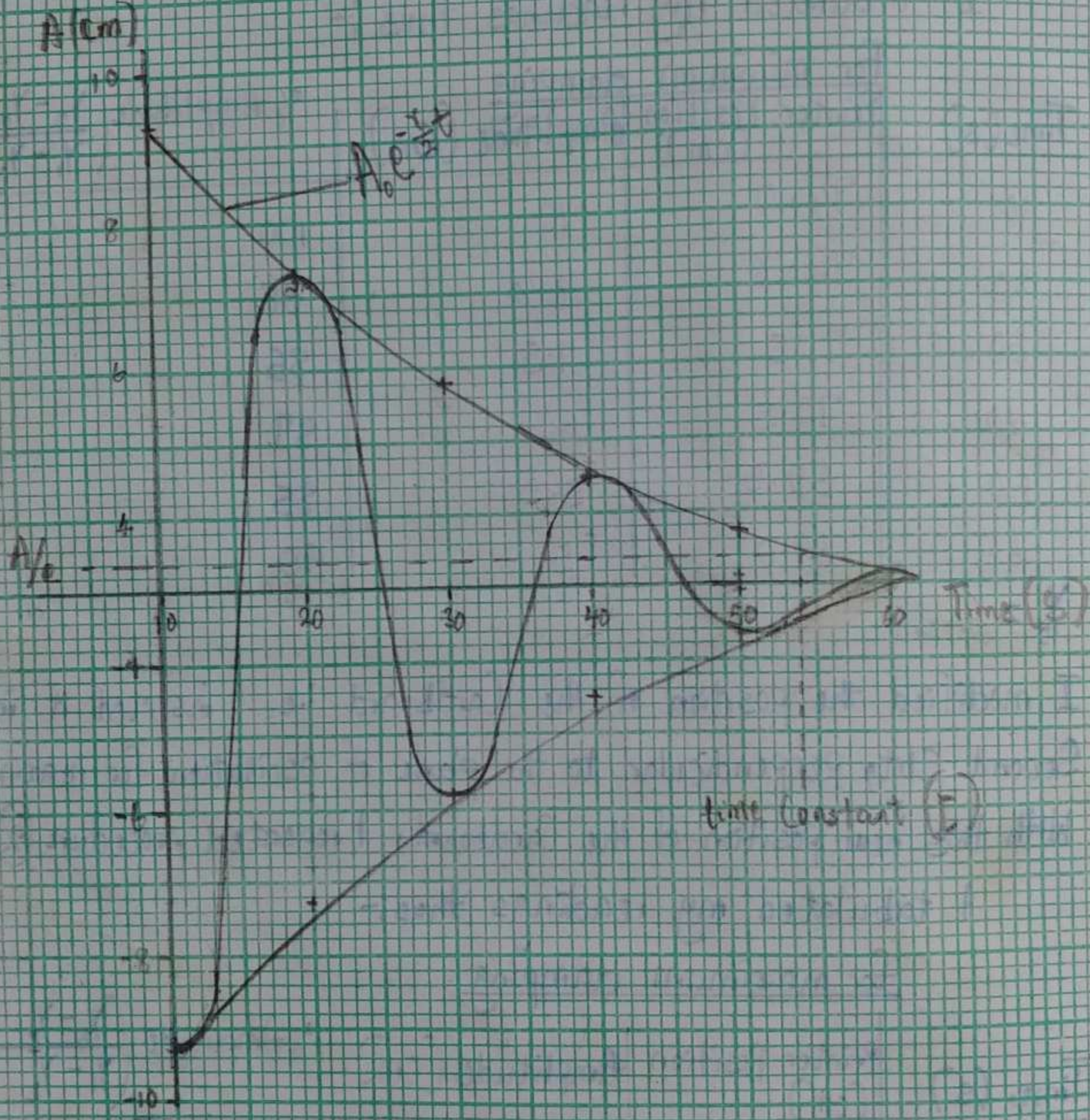
I tabulated my readings thus:-

for maximum damping.

Time (s)	Printer position (cm)	Amplitude (cm)	% Amplitude $\left(\frac{Y_2 - Y_0}{Y_1 - Y_0} \times 100\%\right)$
10	73.3	9.3	100
20	71.3	7.3	79
30	69.8	5.8	79
40	68.5	4.5	78
50	67.7	3.7	82
60	66.9	2.9	78

$Y_0 = 64cm$

Decay Curve for Maximum Damping Scale: 2cm to 2units on y-axis, 2cm to 10units on x-axis



Theory

Most Simple harmonic motions in nature do not have Simple "free" Oscillations. It is more likely there will be Some kind of friction or resistance to damp out the free motion.

The damping (resistance) against the oscillating System Can be adequately described as a function of Speed $\left(\frac{dx}{dt}\right)$ of the oscillating body, hence,

$F = b\,dx/dt$ where b = Coefficient of damping

Another force acting on the body is the restoring force (F_R) which Can be said to be proportional to the displacement, hence

$F_R = kx$; where K = Spring Constant of the vibrating body.

Thus the equation of motion of a damped Oscillating motion of mass (m) is given as;

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + Kx = 0 \quad \text{——— (i)}$$

Equation (i) Can further be written as;

$$d^2x/dt^2 + \gamma\,dx/dt + \omega_0^2 x = 0 \quad \text{——— (ii)}$$ where $\gamma = b/m$

$\omega_0 = \sqrt{K/m}$

Equation (ii) has a Solution of the form;

$x =$

'x' is the Amplitude, where A and $\emptyset$ are Constants of Integration and Can be determined by the initial Conditions.

The angular frequency of the damped System is given by

ω

but ω when b and thus γ (the damping) is relatively Small.

The ratio of the amplitude $x_0, \dots, x_N$ at time $t_0, \dots, t_N$ can be given as

$$x_0/x_N = e^{(t_n - t_0)c}$$

Hence,

$$\tau = \frac{t_N - t_0}{\ln(x_0/x_N)} \quad \text{——— (iv)}$$ where τ = decay time constant.

The **logarithmic decrement** is the natural logarithm of the ratio of two successive displacements maximum (amplitudes). This is constant for amplitude decrease in equal intervals of time.

i.e $\ln \frac{x_1}{x_2} = \ln \frac{x_2}{x_3} = \Delta$

also,

$$\Delta = \gamma T/2$$

but,

$$\tau = 2/\gamma$$

so,

$$\Delta = T/\tau$$

The time constant (τ) is the time taken for the maximum amplitude to decay to $1/e$ (i.e $1/2.7183$) of its initial value.

Result Analysis / Conclusions

1. Determine the time Constant (τ) from the decay Curves. What is the effect of damping on the time Constant.

Ans

* For minimum damping; the value of the amplitude after One time Constant is;

$A/e = 10/2.7183 = 3.6788cm$

The time Constant (i.e time taken to attain this value of A) Cannot be deduced from the decay Curve provided in this report but it is evident (from the decay Curve,) that this Value lies beyond 60seconds — Say 70 seconds.

Thus $\tau \approx 70secs$ [although using the formular $\tau = \frac{(t_N - t_0)}{\ln(X_0/X_N)}$ yields 73secs]

* For Maximum damping; the value of the amplitude after One time Constant is,

$A/e = 9.3/2.7183 = 3.4213$

From the decay Curve it Can be deduced that the time Constant (time taken to attain this value of A,) is 54seconds.

Thus $\tau = 54 secs$

More damping results to a Smaller value of the time Constant (τ) — the Oscillations dies out more quickly. While less damping results to a larger value of τ — the Oscillation will Carry on longer.

2. Find the logarithmic decrement (Δ) for each Case. What is the effect of damping on the logarithmic decrement.

Ans

* For Minimum damping;
logarithmic decrement $(\Delta) = \ln(x_1/x_2) = \ln(10/8.8) = 0.1278$
* For Maximum damping:
Logarithmic decrement $(\Delta) = \ln(x_1/x_2) = \ln(9.3/7.3) = 0.2421$

Thus, it is evident from the results above that an increase in damping results to relative increase in the logarithmic decrement hence, the oscillation dies out more quickly.

Questions

1. Give 3 examples of physical world quantities that decreases with time according to exponential law.

Ans
* Radioctivity: Radioactive elements decays exponentially with time
* Electrostatics: The electric Charge Contained in a Capacitor decreases exponetially with time during discharge.
* Chemistry: The rate of first Order reactions decreases with time (In a closed System).

2. Obtain an expression for half life in terms of logarithmic decrement

$$x = x_0 2^{-t/t_{1/2}}$$

$\ln 2^{t/t_{1/2}} = \ln\left(\frac{x_0}{x}\right)$ but $\ln(x_0/x)$ is the logarithmic decrement (Δ)

Thus,

$$t/t_{1/2} \ln 2 = \Delta$$

Ans => $\therefore$ Half life $(t_{1/2}) = \frac{t \cdot \ln 2}{\Delta}$

Experiment 03: FORCED OSCILLATION OF A DAMPED MECHANICAL SYSTEM.

Aim: To investigate the effect of damping on the resonance Curve of a forced S.H.M

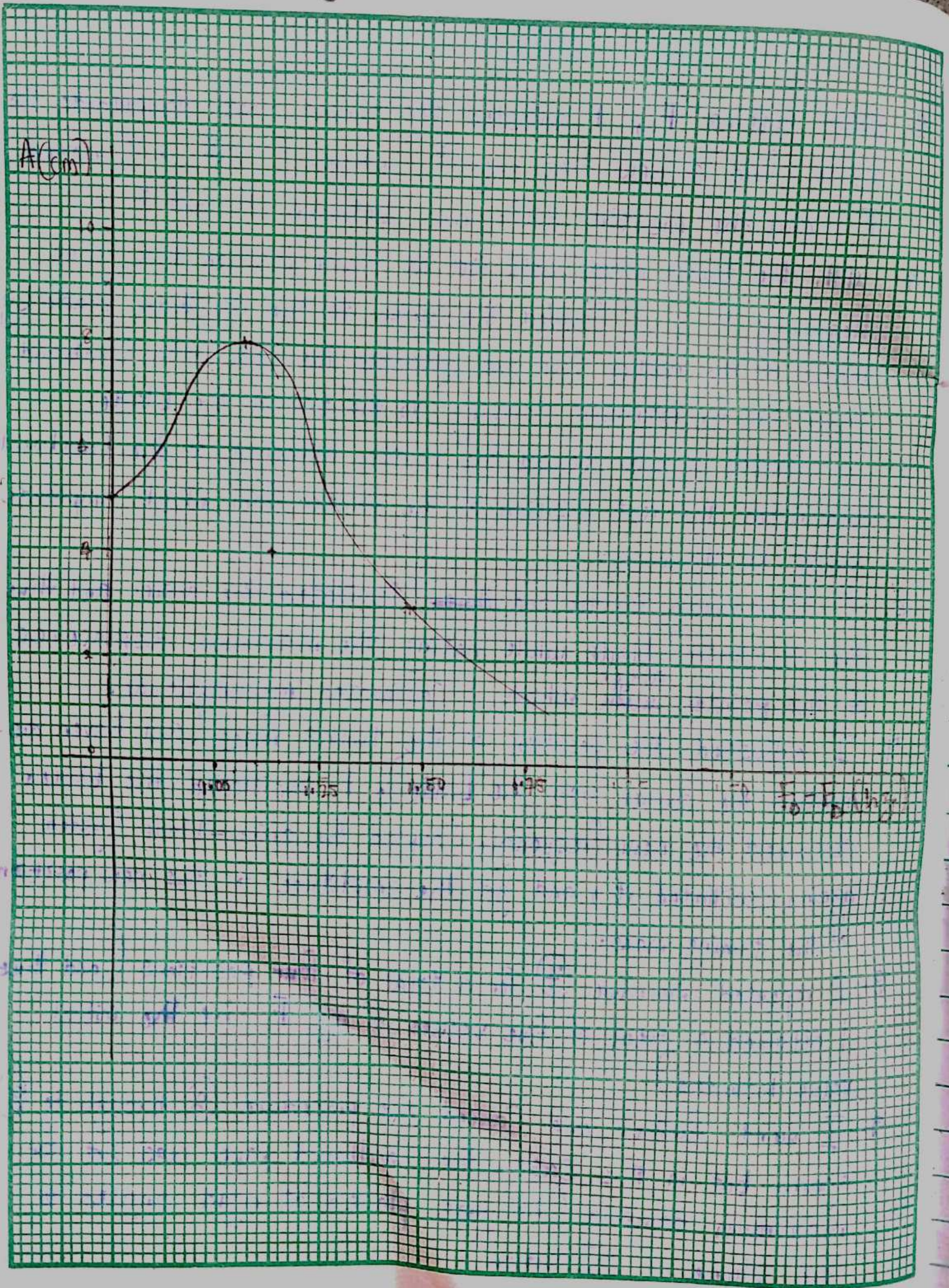
Apparatus:
* A manual Oscillatory driver
* Oscillating blade
* Ruler
* Cardboard with pin — like in Experiment 02
* Cork
* Rubber Cord (elastic) * G-clamp * Tuning mass
* Retort Stand * Base plate * Stop watch

Procedure / Tables of value

1. Setting up the apparatus:
   - i. I Clamped the base plate to the edge of a bench and Clamped the end of the Oscillator blade to the base plate by means of Screws
   - ii. I attached the tuning mass to the blade by feeding the blade between the disc and Securing by means of Screws.
   - iii. I also attached a free Oscillatory driver to the other end of the base plate opposite the Oscillating blade.
   - iv. I Set the Cardboard (with pin) for maximum damping.
2. I made the blade Oscillate while varying the position of the tuning mass at Intervals, to attain a frequency Close to 1 Hertz (F_0).

3. After getting F, I adjusted the tuning mass downwards so as to find a new frequency (F) where F > F. I noted F and the positive difference between F and F.
4. With the tuning mass still set at same position that gave frequency F, I coupled the driver to the oscillator blade by means of the rubber cord and attached the cork (with cardboard paper set for maximum damping) to the tip of the blade.
5. I clamped a ruler behind the pointer attached to the cardboard and noted the rest position of the pointer from which amplitude would be observed.
6. I (continuosly tapped and ~~thus~~) oscillated the driver and thus the oscillator blade while noting the maximum displacement of the pointer ~~with~~ after which I calculated my amplitude.
7. I adjusted the position of the tuning mass (and haven dismantled the driver from the blade), I oscillated the blade, obtained the new frequency, coupled the driver-blade system again, oscillated it, and got the amplitude for this new position of the tuning mass.
8. I repeated procedure 7 for a total of four positions (and thus I attained a total of five values of my F i.e the initial value included).
9. I went further and carried out procedure 2 through to 8 again, but in this case, the cardboard paper was set for maximum damping (i.e was placed at right angles to the plane of oscillation).

Resonance Curve for Minimum Damping



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Tables of Values

For minimum damping:

Amplitude	Time for 50 oscillations	frequency	$F_0 - F_0$
0.5	24.155	2.07	0.75
0.8	31.315	2.39	1.07
0.4	20.475	2.44	1.12
0.3	17.895	2.79	1.47

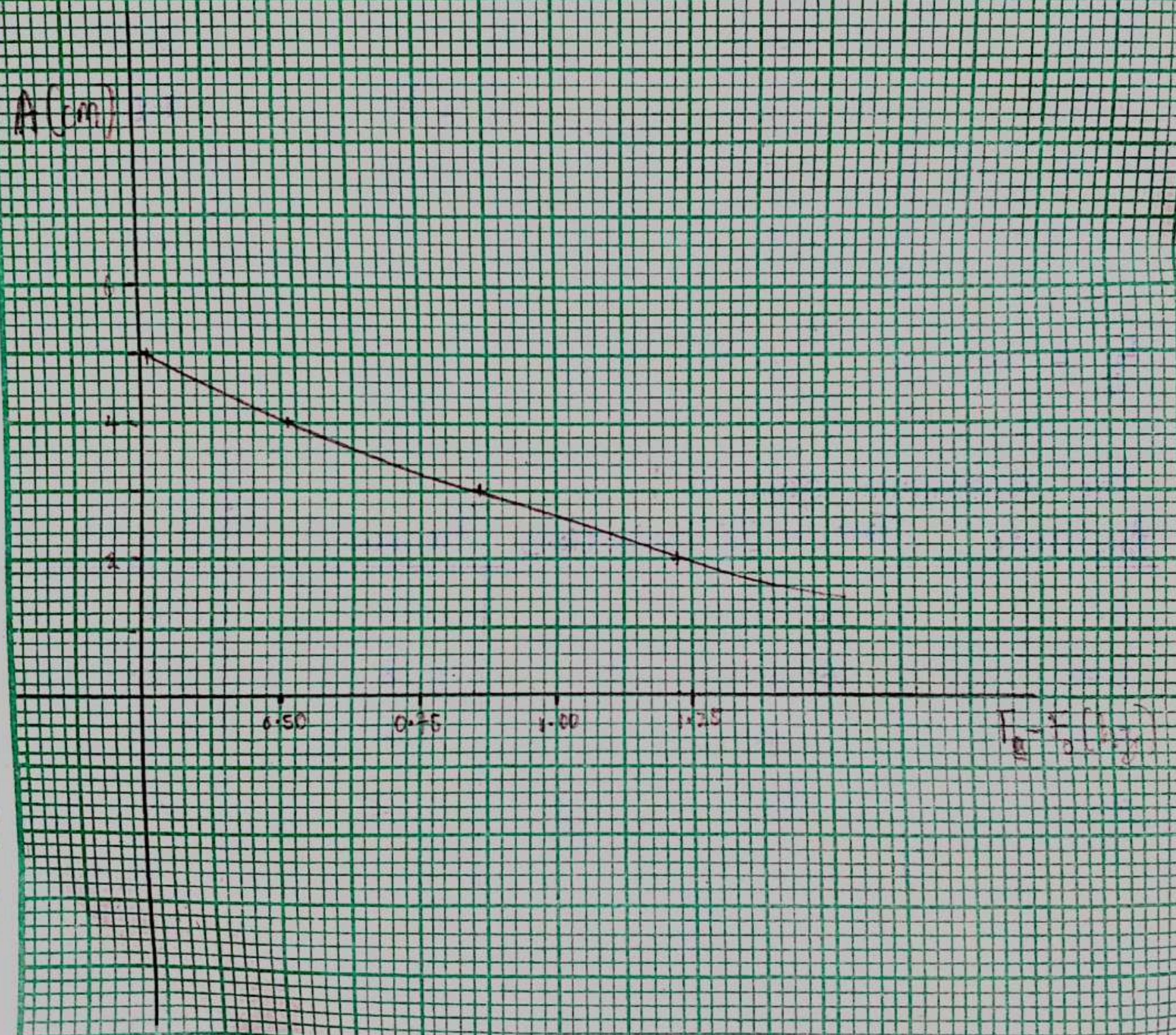
$F_B = 1.32\ Hz$

For maximum damping:

Amplitude	Time for 50 oscillations	frequency	$F_0 - F_0$
0.5	32.025	1.56	0.26
0.4	26.760	1.86	0.56
0.3	23.140	2.16	0.86
0.2	19.700	2.53	1.23

0.025

Resonance Curve for Maximum Damping



Theory

In addition to the restoring force (F_R) and damping force (F_D) in a free-damped oscillatory motion. There exists, in the case of force-damped oscillatory motion, a force which keeps the oscillation from dying out naturally and this force is called a **driving force**. In many cases, the driving force will be sinusoidal in time

The effect of the driving force causes the given solution of the equation of motion (yet to be stated), to be oscillatory. Although, there will likely be a phase difference between the driving term (force) and the response (deflection).

Thus the equation of motion is given as;

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = F_0 \sin\omega t \qquad \text{(i)}$$

Eqn. (i) can further be written as;

$$\frac{d^2x}{dt^2} + \frac{b}{m}\cdot\frac{dx}{dt} + \frac{k}{m}x = \frac{F_0 \sin\omega t}{m}$$

Without proof, it will be stated that a solution to Eqn. (i) (Inhomogeneous equation) can be written as;

where $\varnothing$ = Phase difference

and for $\varnothing < 0$, the response lags behind the driving force.

Inputing Eqn. (iii) in (i) and simplifying further, we get the amplitude (A) of the steady state motion as;

A

and the phase difference ($\emptyset$) is given by;

$\emptyset = \tan^{-1}$

The phase varies as follows;

* When the damping is Small and ω the forced Oscillation is in phase with the driving force.
* When the Oscillation lags behind the driving force by 90° ($\pi/2$ rads)
* When the oscillation is 180° (π rads) out of phase with the driver.

$\emptyset$, the phase difference, is also affected by the value of 'b' (the damping Co-efficient), thus the differences and Similarities between a forced Oscillating System with maximum damping and forced Oscillating System with minimum damping Can be deduced from their resonance Curves.

Precautions.

Conclusions (Comparing/Contrasting the two resonance Curves):

* The resonance Curve for minimum damping has a higher amplitude than the resonance Curve for maximum damping.
* From the resonance Curve for maximum damping ~~we can deduce that~~ we can deduce that the System was (more than) Critically damped while the resonance Curve for minimum damping Shows the System was "less than" Critically damped.
* The minimally damped resonance Curve has ~~a hig~~ maximum amplitude which is unarguably due to resonance. This is not the Case with the maximally damped resonance Curve.
* Both resonance Curves experiences Continuous decrease in amplitude.

In Conclusion, the effect of damping on an Oscilloating System is clearly evident in it's resonance Curve. Thus the Similarities and difference between ~~different~~ Oscilloating Systems (of different damping Coefficients) Can be deduced from their resonance Curves.

Experiment 05: MEASURING VISCOSITY USING STOKE'S METHOD

Aim: To determine the viscosity of a Sample of oil.

Apparatus:
* A long Cylindrical glass vessel Containing the oil Sample.
* Micrometer Screw guage.
* Stop watch
* Ruler
* 5 Small steel balls.
* Rubber bands — for marking distance(s) on the Cylinder

Procedure

1. I measured (with my micrometer Screw guage) the diameter (d) of the balls at two positions on the individual ball Surface and Calculated the mean diameter.
2. I dropped one of the balls through the open end of the Cylinder and measured (with my stopwatch) the time (t) it takes the ball to Sink the given distance (s) marked by two rubber bands at both ends of the Cylinder.
3. I repeated procedure (2) with each of the other balls.

I tabulated my readings thus:

	Mean Diameter (cm)	Radius (r) (cm)	Time (t) (s)	$V = S/t$ (cm/s)	r^2 (cm)^2	S (cm)
Ball 1	0.2580	0.1290	12.78	6.18	0.0166	79
Ball 2	0.3165	0.1583	13.69	5.77	0.0250	79
Ball 3	0.4470	0.2235	5.91	13.37	0.0499	79
Ball 4	0.4750	0.2375	4.40	17.95	0.0564	79
Ball 5	0.6245	0.3123	2.85	27.72	0.0975	79

Theory

Viscosity refers to the friction within a fluid from flowing freely and is essentially a frictional force between different layers of fluid as they move past one another. The tangential force (f) required to move a layer of area S and located a perpendicular distance (x) from an immobile Surface is given by

$F = \eta \frac{dv}{dx} S$ where η is the Coefficient of viscosity

Provided the velocity of the flow is not too large and the fluid flows Smoothly, the flow is Said to be laminar.

The mutual influences of layers of fluid which move past one another are Conditioned by the molecule Intermediate fluid attraction. This also prevents motion of a Solid body in fluid because the whole Surface of the body is Covered with thin molecular layers of the fluid. Therefore force of viscosity resists motion of a body in fluid, this is only possible when the velocity of the body is Smaller than the velocity of the fluids laminar flow otherwise whirls will arise and the formula, $F = \eta \frac{dv}{dx} S$ would no longer be useful.

In general it is Complicated to find the formula of frictional force (f). In case of regular bodies, this problem Can be Simplified for Spherical bodies. Stoke derived the formula

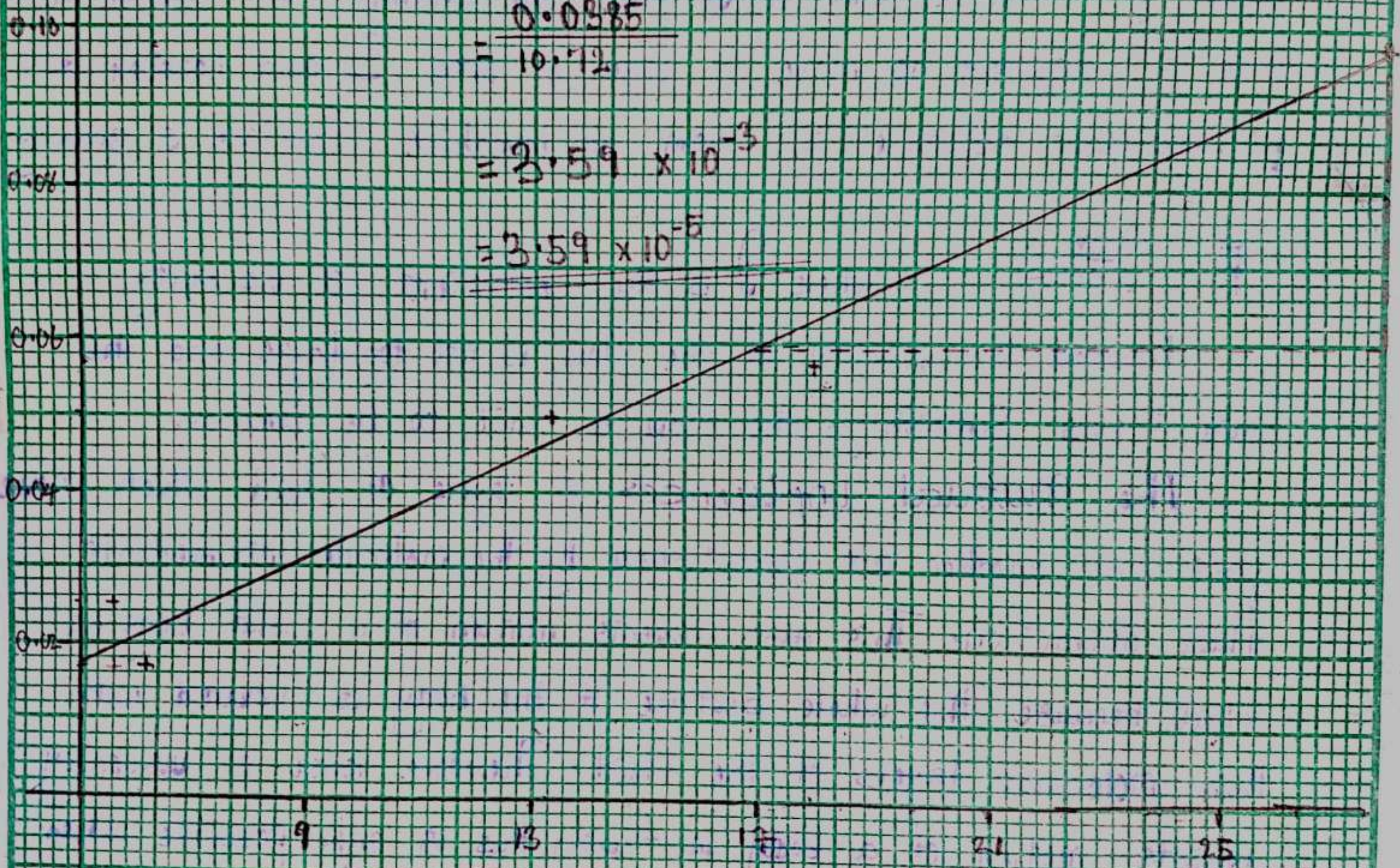
$$\text{Slope} = \frac{\Delta y}{\Delta x} = \frac{\Delta r^2}{\Delta V}$$

$$= \frac{0.0975 - 0.059}{27.72 - 17}$$

$$= \frac{0.0385}{10.72}$$

$$= 3.59 \times 10^{-3}$$

$$= 3.59 \times 10^{-5}$$



There are 3 forces acting on a Spherical ball dropped into a liquid:

1. The force of gravity

$F_1 = mg = Vg\rho$ where V = Volume of Sphere
g = acceleration due to gravity
ρ = Density of Sphere

2. Buoyancy force

$F_2 = Vg\rho_0$; where ρ_0 = bouyancy of the liquid.

3. Viscous Drag force

$F_3 = 6\pi\eta rv$

Both F_2 and F_3 act upwards on the body while F_1 acts downwards on the body.

By Summing forces in the vertical direction, the following equations can be written:

$F_1 = F_2 + F_3$

Or,

$Vg\rho = Vg\rho_0 + 6\pi\eta rv$ --- (ii) but $V = \frac{4}{3}\pi r^3$

Substituting $V = \frac{4}{3}\pi r^3$ in then rearranging and regrouping the terms, we would arrive at

$$\eta = \frac{2r^2(\rho - \rho_0)g}{9v} \quad \text{----- (iii)}$$

The formula above is for an infinite volume of liquid. But Since in reality (experiment) we make do of a definite Sized vessel, the following Corrections by Ladeburg needs to be taken into account

* For finite radius, multiply F_3 by $(1 + 2.4\, r/R)$
* For finite length, multiply F_3 by $(1 + 3.3\, r/h)$

By implication, the viscous force acting on a body dropped in a liquid containing vessel is higher than that in an infinite volume of liquid.

Thus, the coefficient of viscosity of a liquid in a cylindrical vessel of radius r and height h, is given as

$$\eta = \frac{2(\rho - \rho_s)\, g r^2}{9V(1+2.4\, r/R)(1 \cdot 3.3\, r/h)}$$

Precautions.

Precautions.

Conclusions

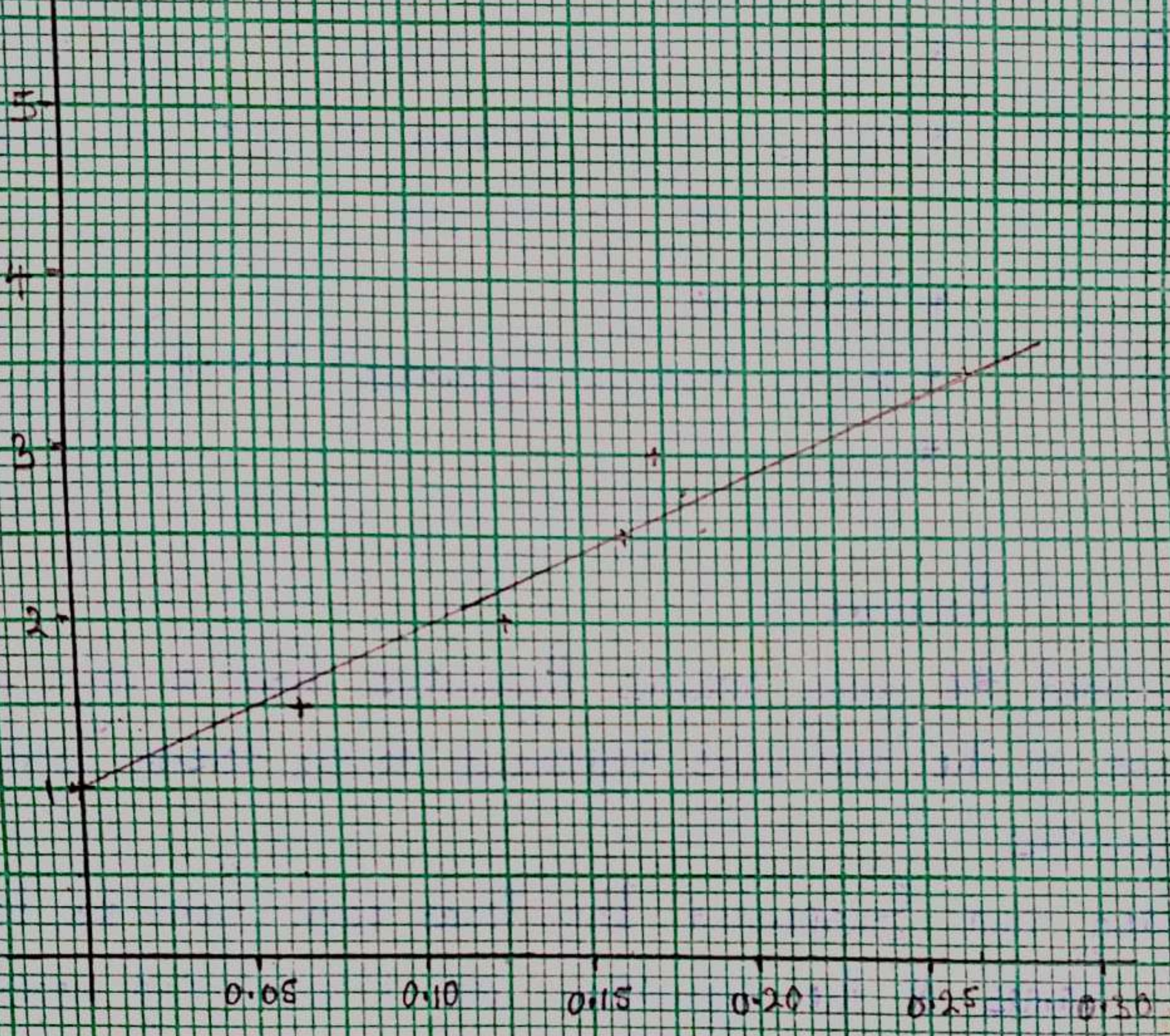
Experiment 08: YOUNG's MODULUS

Aim: To determine Young's Modulus of a wire

Apparatus:
* Two wires of equal length and material
* Weights — 2 masses of 1kg each and 5 masses of 0.5kg each
* Metre rule
* Young's Modulus Apparatus (Y.M.A)
*

Procedure

1. I Suspended the young modulus Apparatus from a rigid frame by means of the two wires tightened to the torsion Screw of the apparatus.
2. I loaded and Suspended 1kg loads each from the hooks of both frames of the apparatus and I took/noted measurement of the length of the wire attached to the frame of the Y.M.A that has no micrometer graduation (F_1)
3. I took measurement of the wire's diameter at various positions along the wire with a micrometer Screwguage and Calculated the average diameter which I further used to Calculate the area of the wire.
4. With both frames equally loaded, I balanced the bubble of the Y.M.A to a Central position (the middle
The Scale reading of the Y.M.A micrometer was noted as the zero weight reading.
5. I added a 0.5kg weight to the load at F_1, the air bubble moved away from the Center So I adjusted the Spherometer


5
4
3
2
1
0.05
0.10
0.15
0.20
0.25
0.30

Screw so that it Comes back to the Central position, then I took note of the new reading of the micrometer and Calculated the extension In the wire as the positive difference between the 'Zero weight' reading and the new reading.

6. I Continued to Increase the load at F_1 by 0.5kg, while Stopping to adjust the bubble to the middle and take note of the new readings at each 0.5kg Increment. I repeated this process till I attained a total mass of 3.5kg at F_1 and thus had a total of Six different values for the extension In the wire.

I tabulated my readings/Observations/results. My table appeared thus:

Weight (kg)	Vernier reading (cm)		Mean (cm)	Extension (cm)
1.0	0.786	0.786	0.786	0
1.5	0.850	0.850	0.850	0.064
2.0	0.913	0.913	0.913	0.127
2.5	0.949	0.949	0.949	0.163
3.0	0.959	0.959	0.959	0.173
3.5	1.052	1.052	1.052	0.266

$D_1 = 0.57mm$

$D_2 = 0.58mm$

$D_3 = 0.57mm$

$D_4 = 0.60mm$

$D_5 = 0.58mm$

Initial length of wire = 262cm

Mean diameter $\doteq 0.58mm \pm 0.005$

Theory

If a force (F) is applied to a wire of length (L), it stretches an amount ΔL and if ΔL is Small So that the Cross-Sectional area (A) remains Constant, the tensile Stress (force exerted per Unit area) Can be defined mathematically as;

$$Stress = F/A$$

While the tensile Strain (i.e distortion per Unit dimension of the wire) is given as:

$$Strain = \Delta L / L$$

Within the elastic limit (Hooke's law is valid), the ratio of the tensile Stress to strain is Called Young's Modulus of the wire (Young's Modulus is the material property that determines it's stiffness and elasticity). Young's Modulus is given mathematically as

$$Y = \frac{stress}{Strain} = \frac{F/A}{\Delta L / L}$$

Precautions.

Conclusions

DATE

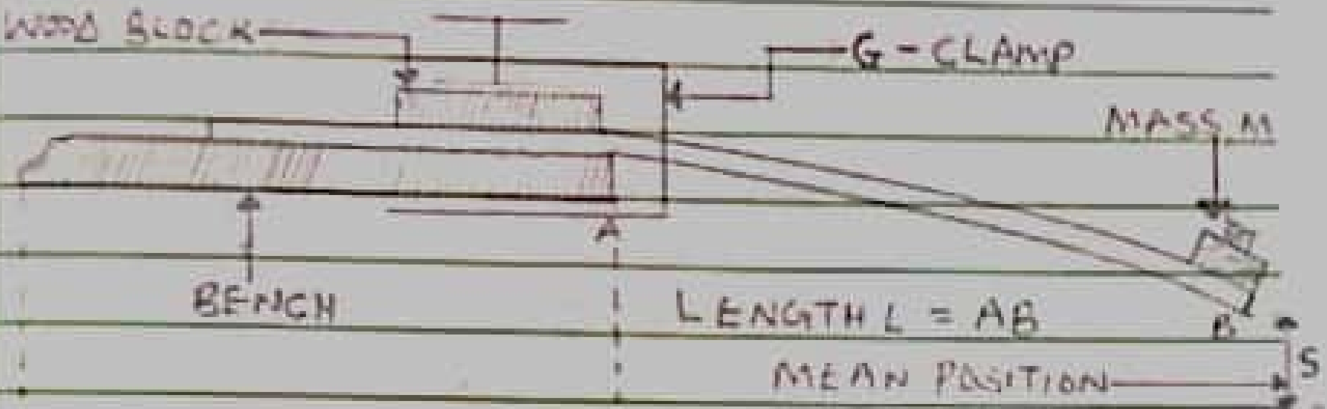
EXPERIMENT 04

TITLE: Young's Modulus of wood using a cantilever.

AIM: To determine the Young's modulus of wood along the grain using a cantilever.

APPARATUS: Wooden metre rule, 100g mass, a bench, G-clamp, block of wood, Vernier callipers and stopwatch.

DIAGRAM:



PROCEDURE

1. I clamped the loaded metre rule firmly to the end of a bench with a definite length, L projecting from the edge of the bench.
2. I started the metre rule vibrating vertically and I determined the periodic time, T, for one complete oscillation. I did this by timing 20 oscillations and divided by 20. I determined, T for the following lengths - 50cm, 40cm, 60cm, 70cm & 80cm. I tabulated the readings of L and T
3. Using the callipers, I measured the dimensions

A [illegible] of the metre rule. I [illegible] six readings for [illegible] at different positions along the rule. I recorded the readings then calculated the mean values of b and d.

OBSERVATIONS

M = mass at end of the metre rule = 2.5 kg

6 readings for breadth of the metre rule =
0.0268m, 0.0267m, 0.0269m, 0.0268m, 0.0267m, 0.026[illegible]

Average breadth = 0.0268m

6 Readings for depth of the metre rule =
0.0085m, 0.0083m, 0.0084m, 0.0086m, 0.0085m, 0.0084m

Average depth = 0.0085m

TABULATIONS

Length (cm)	t (s)	$T = t/20$ (s)	T^2 (s^2)	L^3 (cm^3)
80.0	9.70	0.4850	0.2352	512000.0
70.0	8.01	0.4005	0.1604	343000.0
60.0	6.49	0.3245	0.1053	216000.0
50.0	5.30	0.2650	0.0702	125000.0
40.0	4.82	0.2410	0.0581	64000.0

THEORY

Bending theory gives $s = \frac{4FL^3}{bd^3E}$

where F is a force applied to the end of the metre rule and E is known as the Young's modulus. Thus if the rule is depressed a distance, s, from equilibrium the restoring force is:

$$F = -\frac{bd^3Es}{4L^3} = -ks \quad \text{where } k = \frac{bd^3E}{4L^3}$$

This force acts on the mass at the end of the rule. Ignoring the mass of the metre rule itself, the following is derived:

$f = Ma = -ks$ and therefore $a = -\frac{ks}{M}$

The solution to this equation comes from the theory of simple harmonic motion. The equation describes an oscillation with $\omega^2 = k/m$. In terms of the period this is:

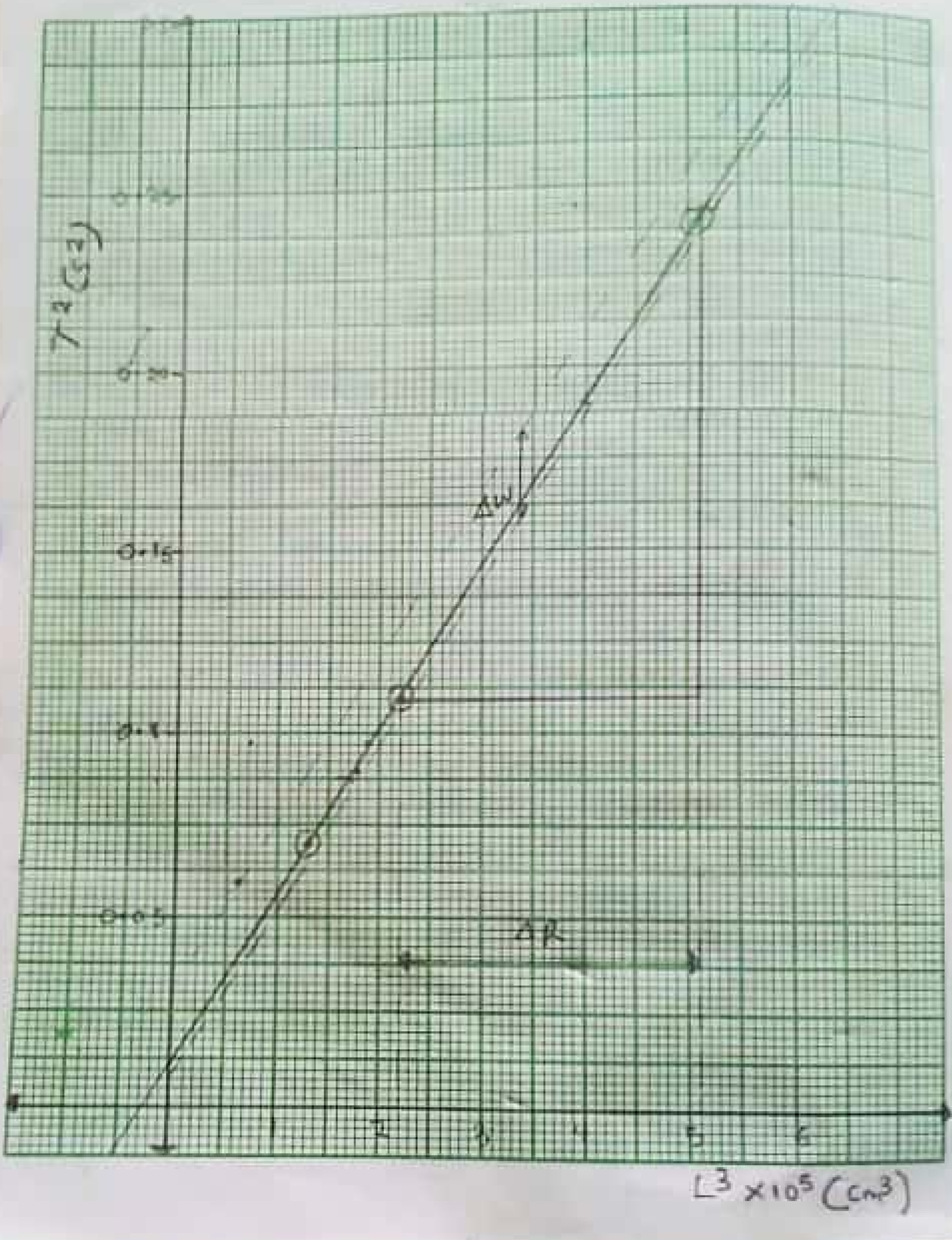
$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{M}{k}}$$

Therefore:

$$T^2 = \frac{4\pi^2 M}{k} = \frac{16\pi^2 ML^3}{bd^3E}$$

$$T^2 = \frac{16\pi^2 ML^3}{bd^3E}$$

$$E = \frac{16\pi^2 ML^3}{bd^3T^2} = \frac{16\pi^2 M}{bd^3} \times \frac{1}{\text{slope}}$$



T^2 (s²)
0.25
0.20
0.15
0.10
0.05
ΔW
ΔR
1
2
3
4
5
6
$L^3 \times 10^5$ (cm³)

CALCULATIONS

$$Slope = \frac{\Delta T^2 (s^2)}{\Delta l^3 (cm^3)}$$

$$= \frac{(0.2352 - 0.1053)\,s^2}{(512000 - 216000)\,cm^3}$$

$$= 4.39 \times 10^{-7}\ s^2/cm^3$$

$$= 0.439\ s^2/m^3$$

Given that

$$E = \left(\frac{16\pi^2 M}{bd^3}\right) \times \frac{1}{slope}$$

where $M = 2.5kg$.

$b = 0.0268m$

$d = 8.5 \times 10^{-3} m$

$Slope = 0.439$

Therefore

$$E = \left(\frac{16 \times (3.142)^2 \times 2.5}{0.0268\,(8.5 \times 10^{-3})^3}\right) \times \frac{1}{0.439}$$

$$= 5.46 \times 10^{10}\ Nm^{-2}$$

ERROR ANALYSIS

Table of Errors

Quantitative Symbol	Value	Error	Relative Error	Square of Relative Error
M	2.5 kg	± 0.0001	1.406×10^{-5}	1.9762×10^{-6}
R	0.0268 m	± 0.001	0.0741	1.978×10^{-4}
d	8.5×10^{-2} m	± 0.001	0.0141	1.9551×10^{-4}
dT^2/dR	0.439	± 0.069	0.19705	0.941%

Derivation of the expression for the error in E from

$$E = \frac{16\pi^2 M}{B d^3} \times \frac{1}{\text{slope}}$$

$$\left[\frac{S_E}{E}\right]^2 = \left[\frac{S_M}{M}\right]^2 + \left[\frac{S_B}{B}\right]^2 + 3\left[\frac{S_d}{d}\right]^2 + \left[\frac{S_s}{s}\right]^2$$

where s = slope

$$\frac{S_E^2}{(5.410\times10^{10})^2} = \left(\frac{0.0001}{2.5}\right)^2 + \left(\frac{0.001}{0.0268}\right)^2 + 3\left(\frac{0.001}{8.5\times10^{-2}}\right)^2 + \left(\frac{0.069}{0.439}\right)^2$$

$$S_E^2 = (2.9812\times10^{21})\left[1.6\times10^{-9} + 1.3923\times10^{-3} + 0.042 + 0.025\right]$$

$$S_E^2 = 2.9812\times10^{21} \times 0.0684$$

$$S_E^2 = 2.039\times10^{20}$$

$$S_E = \sqrt{2.039\times10^{20}}$$

$S_E = \pm 1.428 \times 10^{10}$

RESULT

The Young's modulus of wood along the grain using a cantilever is $(5.46 \pm 1.43) \times 10^{10}\ Nm^{-2}$