GOVERNMENT ARTS AND SCIENCE COLLEGE NADAPURAM
UNIVERSITY OF CALICUT

GOVERNMENT ARTS & SCIENCE COLLEGE NADAPURAM

LAB MANUAL FOR PHYSICS(MAJOR)

FYUGP- SEMESTER 1

NUMBER OF EXPERIMENTS: 7

1. **Young's Modulus of the the Material of a Given Bar: Uniform Bending**
    - Use an optic lever and telescope. Take measurements for a minimum of two lengths.
    - Obtain the elevation (e) from the shift (s) in the telescope reading and calculate Y from it.
    - For each length of the bar, plot the load-elevation graph (using GeoGebra) and obtain m/e, and then calculate Y from it.
    - Estimate the random error in the measurements and the error of the result using propagation of the error formulae.
2. Y**oung's Modulus of the Material of a Given Bar: Non-Uniform Bending**
    - Use a pin and a microscope. Take measurements for a minimum of two lengths.
    - Obtain the depression (e) from the Shift in the microscope reading and calculate Y from it.
    - For each length of the bar, plot the load-depression graph (using GeoGebra) and obtain m/e, and then calculate Y from It.
    - Estimate the random error in the measurements and the error of the result using propagation of the error formulae.

3. **Coefficient of Static Friction: Determine the coefficient of static friction between a wooden block and a wooden plane.**
    - Measure the angle at which the wooden block just starts to slide down an inclined wooden plane and hence calculate the static friction coefficient.

4. **Acceleration of a Freely Falling Body**
    - Use the smartphone acoustic stopwatch to determine the duration of a free fall.
    - Measure the time of flight of a steel ball for different heights and plot a graph of distance versus. time squared (s vs. T^2).
    - Determine g from the graph.
    - Phyphox app may be used.

5. **Analysis of Bouncing Balls to Determine Gravitational Acceleration and Coefficient of Restitution.**
    - After doing the experiment, the student should be able to understand the concept of inelastic collision.
    - Measure the time interval between successive bounces using a digital acoustic stopwatch and hence calculate g and coefficient of restitution
    - Phyphox app may be used.

6. **The Nearly Parabolic Trajectories of a Bouncing Ball Perform Experiment 7 using Tracker tool.**
    - Track the BOUNCING BALL BY TAKING VIDEO and plot the time versus position graph.
    - Measure the time interval between successive bounces and hence calculate g and coefficient of restitution. (TRACKER)

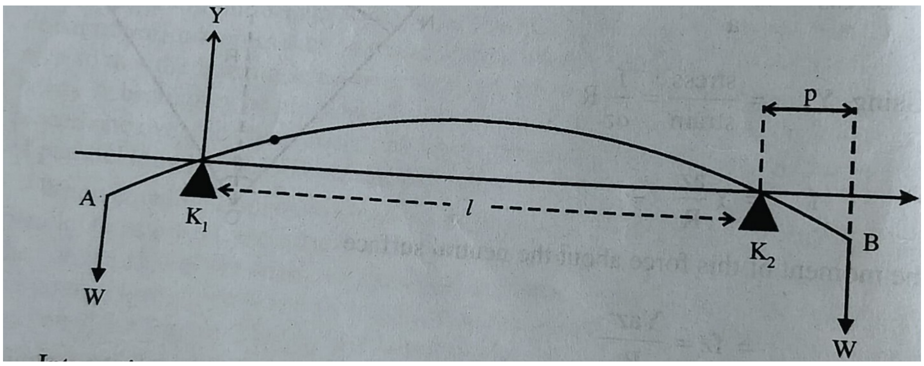
7. **Analysis of Air Resistance and Terminal Speed to Determine the Drag Coefficient.**
    - Record the motion of a light weight paper cup and analyse it with Tracker tool (https://physlets.org/tracker/).
    - Plot acceleration, velocity, and position with time.
    - Repeat the experiment with different mass (by simply stacking the paper cups)
    - Determine the Drag Coefficient

1. Young's Modulus of the Material of a Given Bar: Uniform Bending

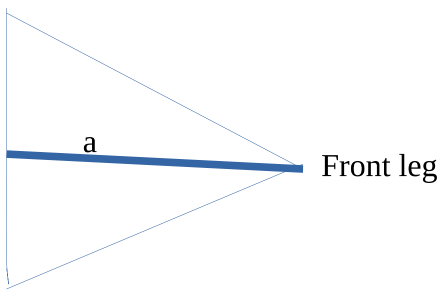
Aim:
To determine Young's modulus of the material of the given bar by subjecting to uniform bending using optic lever for measuring the elevation at the midpoint of the bar

Apparatus:
A long uniform bar (usually a metre scale made of wood or iron), Two weight hangers with slotted weights, metre scale, optic lever, scale and telescope arrangement, use continuous scale with 'zero' at one end

Theory:
A beam is a straight rod or bar of uniform cross section whose length is large when compared with cross section area so that the bearing stress over its cross section are negligibly small. When equal and opposite couples are applied at the ends of a beam in a plane parallel to its length, the beam bends into a circular arc. In bending the filaments of the convex side of the beam are extended in length, while those of the concave side are compressed, there is however a plane in the beam in which the filaments remain unchanged in length. This is called neutral surface.
When a beam is bent under the action of equal and opposite couple at its ends, an internal elastic restoring couple is developed within the beam due to the extension and contraction of its filaments. This internal couple developed is called **bending moment**. When the beam is in equilibrium the external couple is equal to the bending moment.



Optic lever consist of three legs on a metal strip and consist of a plane mirror on it. Place this on a paper and measure the distance 'a',



Young's modulus of the material is $Y=\frac{mgpl^2}{8Ie}$ where 'm' is the load attached, 'p' is the distance from knife edge to the mass hanged, 'l' is the distance between knife edges, 'I' is the moment of inertia of the bar and 'e' is the elevation produced by loading the mass.

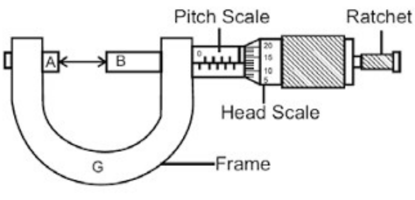
The moment of inertia of the bar $I=\frac{bd^3}{12}$ where 'b' is the breadth and 'd' is the thickness of the bar. So $Y=\frac{3mgp}{2bd^3}(\frac{l^2}{e})$. Let 'D' is the distance between scale and mirror and 's' is the shift in the scale reading due to the load, elevation'e' is,

$$e=\frac{sa}{2D}$$

Procedure:

The bar whose modulus is to be determined is supported symmetrically on two knife edges with a length (say 60 cm) between the knife edges. Then weight hangers are suspended symmetrically from the knife edges. Load and unload the har two or three times. Thus the bar is brough to the elastic mood. **A platform or another bar is arranged near the experimental bar, without touching it. Place a single optic lever with its single leg at the centre of the experimental bar B, and the other two legs on the auxiliary bar B.**
A telescope and a vertical scale are arranged at a distance of 1m from the optic lever. Adjust the height of the telescope so that its axis passes through the centre of the mirror. Focus the telescope on the image of the scale formed by the mirror. With zero load, take the reading corresponding to the point of intersection of the cross wires. Increase the load in steps, each time noting the reading. The weights are removed one by one and the readings are again taken. The average telescope reading for each load is found. Calculate the shift in scale reading for a constant load 'm'. Find the mean shifts.
Tabular columns:

1. To find the thickness of the bar using screwgauge



Pitch =…..cm (distance travelled in pitch scale during one rotation of screw gauge)
Total number of divisions on head (circular) scale=……..
Least count of screw gauge (LC)= pitch/no. Of divisions on head scale=……..cm
Zero correction =………..div

S.no	Pitch scale reading(PSR) (a)	Head scale reading(HSR) (b)	Corrected HSR=HSR+zerocorrection (c)	Total=a+(c x LC) cm
1 2 3 4 5				

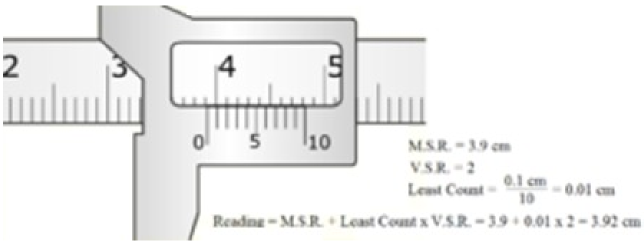
Mean d = ...cm

2. To find $\frac{l^2}{e}$

Length (l)	Load(weight) kg	Telescope reading			Shift for 3m	Shift for m	Mean shift (s in cm)	Elevation $e = \frac{sa}{2D}$	
		Loading	Unloading	Mean(cm)					
l=......	W_0 W_0+m W_0+2m W_0+3m W_0+4m W_0+5m W_0+6m W_0+7m			a_0 a_1 a_2 a_3 a_4 a_5 a_6 a_7	$S_1=a_3-a_0$ $S_2=a_4-a_1$ $S_3=a_5-a_2$ $S_4=a_6-a_3$ $S_5=a_7-a_4$	$S_1/3$ $S_2/3$ $S_3/3$ $S_4/3$ $S_5/3$	s		$\frac{l^2}{e}$ =
l=......	W_0 W_0+m W_0+2m W_0+3m W_0+4m W_0+5m W_0+6m W_0+7m								$\frac{l^2}{e}$ =

Mean $\frac{l^2}{e}$ = -----------

3. To find the breadth of the bar :



Value of one main scale division=............
No of divisions on the vernier=..........
LC= Value of one main scale division/No of divisions on the vernier
=.........cm

s.no	Main scale reading(MSR)	Vernier scale reading(VSR)	Total=MSR+(VSR x LC)
1 2 3 4			

Mean b =.........cm

a = ----------cm

$$Y=\frac{3mgp}{2bd^3}\left(\frac{l^2}{e}\right)$$

D = -------- cm

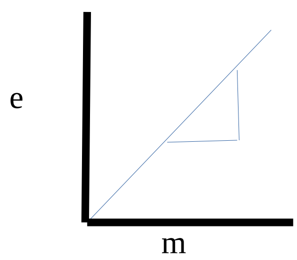
m = --------kg

4. To find $\left(\frac{m}{e}\right)$

Length (l)	Load(weight) kg	Telescope reading			Shift for each mass	Mean shift (s in cm) $e=\frac{sa}{2D}$	$\left(\frac{m}{e}\right)$
		Loading	Unloading	Mean(cm)			
l=......	W_0 W_0+m W_0+2m W_0+3m W_0+4m W_0+5m W_0+6m W_0+7m			a_0 a_1 a_2 a_3 a_4 a_5 a_6 a_7	$s_1=a_1-a_0$ $s_2=a_2-a_0$ $s_3=a_3-a_0$ $s_4=a_4-a_0$ $s_5=a_5-a_0$ $s_6=a_6-a_0$ $s_7=a_7-a_0$		
l=......	W_0 W_0+m W_0+2m W_0+3m W_0+4m W_0+5m W_0+6m W_0+7m						

Draw a graph between 'm' and 'e' (using Geogebra) by taking mass along X axis and elevation along Y axis and the slope of the curve give e/m . Then

$$Y=\frac{3gpl^2}{2bd^3}\left(\frac{m}{e}\right) \text{ gives } Y=\frac{3gpl^2}{2bd^3}\left(\frac{1}{slope}\right)$$



Result : Young's modulus of the material of given bar,

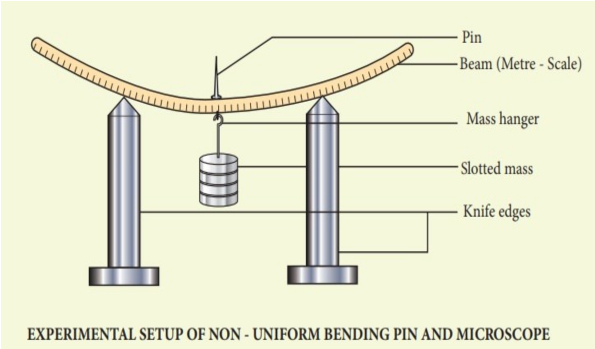
By calculation = --------------------

From the graph = -------------------

2. Young’s Modulus of the Material of a Given Bar: Non-Uniform Bending

Aim : To determine Young’s modulus of the material of the given bar subjected to non uniform bending using pin and microscope method and draw load-depression graph .

Theory:



Young's Modulus (also known as the **modulus of elasticity**) is a mechanical property of a material that measures its stiffness or resistance to elastic deformation under an applied load. It quantifies the relationship between **stress** (force per unit area) and **strain** (proportional deformation) in a material when it is stretched or compressed within its elastic limit. Young’s Modulus tells you how much a material will stretch or compress when a force is applied to it. A higher Young's Modulus indicates that the material is **stiffer** and less prone to deformation, while a lower value means the material is more **flexible** or **elastic**.

$$Y = \frac{Stress}{Strain}$$

The Young’s modulus can be calculated by using

$$Y = \frac{mg}{4bd^3} \times \left(\frac{l^3}{y}\right)$$

where ‘m’ is the mass added, ‘b’ is the breadth of the bar, ‘d’ is the thickness of the bar, ‘l’ is the length between knife edges, and ‘y’ is the depression(extension) for ‘m’.

Procedure:

The given bar is supported on two knife edges at a suitable distance say 40cm(*l*). A weight hanger is suspended from the center of the bar. A pin is fixed vertically at the center of the bar. A microscope is focused at the tip of the image of the pin. Before starting the measurements bring the bar to an elastic mood. For this weights are added on the weight hanger in steps and then unloaded. This is done two or three times. Now the experimental set up is ready for use.

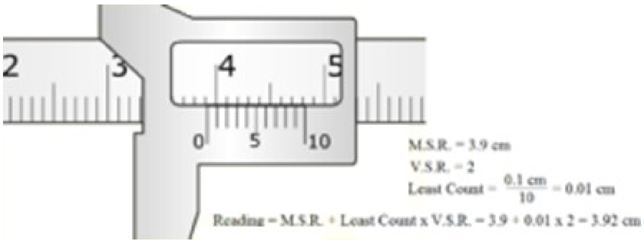
To start with the experiment a dead load W_0 is suspended then the microscope is focused at the tip of the image of the pin. The horizontal cross wire is made to coincide with the tip. The main scale reading and the vernier scale coincidence of the vertical scale of the microscope are noted. Then the total reading = main scale reading + (vernier scale coincidence x least count). Weights are added in steps of m kg, each time note the microscope readings. The average reading corresponding to each load is calculated. From these readings the average depression y for a load of m kg is found.

The experiment is repeated for different values of *1*. In each case the value of $\frac{l^3}{y}$ is found out. For a given load , $\frac{l^3}{y}$ is found to be a constant. The breadth of the bar is found out by a vernier calipers. The thickness d is found out using a screw gauge. Using the formula can be calculated.

Also load depression graph is drawn taking load long x-axis and depression along y-axis.a. Corresponding m/e is found out from the graph in S.I units. Then using the formula $Y=\frac{g\,l^3}{4\,bd^3}\times(\frac{1}{slope})$ Young's modulus is calculated. Repeat this for different lengths, *l* and in each case load-depression graph is drawn. Calculate 'Y' as before in each case. Then find the mean value of 'Y'.

Observation:

1. To find the breadth of the bar :



Value of one main scale division=...........
No of divisions on the vernier=..........
LC= Value of one main scale division/No of divisions on the vernier
=.........cm

s.no	Main scale reading(MSR)	Vernier scale reading(VSR)	Total=MSR+(VSR x LC)
1 2 3 4			

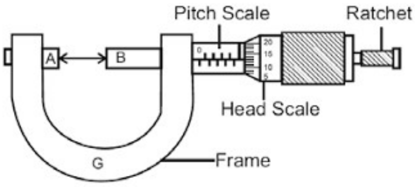
Mean b =.........cm

2. **1. To find the thickness of the bar**

Pitch =…..cm (distance travelled in pitch scale during one rotation of screw gauge)
Total number of divisions on head (circular) scale=……..
Least count of screw gauge (LC)= pitch/no. Of divisions on head scale=……..cm
Zero correction =………..div

S.no	Pitch scale reading(PSR) (a)	Head scale reading(HSR) (b)	Corrected HSR=HSR+zerocorrection (c)	Total=a+(c x LC) cm
1 2 3 4 5				

Mean d = ...cm



3. To find $\frac{l^3}{y}$

Least count of the microscope=……………….

Length 'l' (m)	Mass in 'kg'	Microscopic reading							Depression for '3m' in metre	Mean depression for '3m' in metre	Mean depression for 'm' in metre 'y'	$\frac{l^3}{y}$
		On loading			On unloading			**Mean**				
		M.S.R	V.S.R	Total	M.S.R	V.S.R	Total					
l=0.4	W_0 W_0+m W_0+2m W_0+3m W_0+4m W_0+5m W_0+6m W_0+7m								W_0+3m -W_0= W_0+4m -(W_0 +m)= W_0+5m -(W_0 +2m)= W_0+6m -(W_0 +3m)= W_0+7m -(W_0 +4m)=			
l=0.5	W_0 W_0+m W_0+2m W_0+3m W_0+4m W_0+5m W_0+6m W_0+7m											

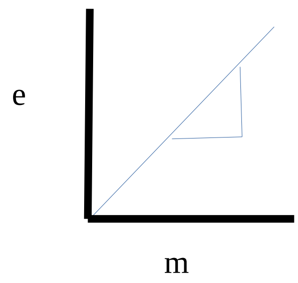
$$Y = \frac{mg}{4\,bd^3} \times \left(\frac{l^3}{y}\right)$$ **=------------N/m²**

4. To find $\left(\frac{m}{e}\right)$

Length (l)	Load(weight) kg	Telescope reading			Shift for each mass	$\left(\frac{m}{e}\right)$
		Loading	Unloading	Mean(cm)		
l=......	W_0			a_0		
	W_0+m			a_1	$e_1=a_1-a_0$	
	W_0+2m			a_2	$e_2=a_2-a_0$	
	W_0+3m			a_3	$e_3=a_3-a_0$	
	W_0+4m			a_4	$e_4=a_4-a_0$	
	W_0+5m			a_5	$e_5=a_5-a_0$	
	W_0+6m			a_6	$e_6=a_6-a_0$	
	W_0+7m			a_7	$e_7=a_7-a_0$	
l=......	W_0					
	W_0+m					
	W_0+2m					
	W_0+3m					
	W_0+4m					
	W_0+5m					
	W_0+6m					
	W_0+7m					

Draw a graph between 'm' and 'e' (using Geogebra) by taking mass along X axis and elevation along Y axis and the slope of the curve give e/m . Then

$$Y = \frac{g\,l^3}{4\,bd^3} \times \left(\frac{1}{slope}\right)$$



Result : Young's modulus of the material of given bar,

By calculation = --------------------

From the graph = -------------------

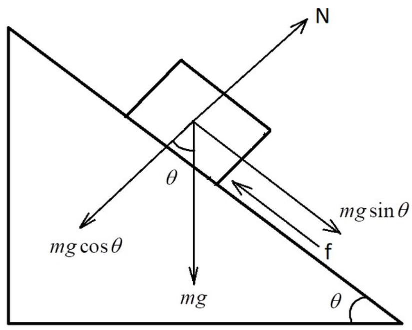
3. Coefficient of Static Friction.

Aim: 1) Determine the coefficient of static friction between a wooden block and a wooden plane.

2) Determine the coefficient of static friction between different objects and a wooden plane.

Theory:

Static friction is **a force that resists the relative motion of two solid surfaces in contact.** When a body is on the surface of a material , the frictional force acting on it is $f_s = \mu_s N$ where μ_s is the coefficient of static friction and N is the normal force (contact force) between two surfaces, which is perpendicular to the plane of contact.



The angle θ is the angle of inclination of a surface at which a mass just begins to slide. At this point, the force of static friction is exactly balanced by the component of the gravitational force pulling the mass down the inclined plane. The component of gravitational force parallel to the incline is *mgsinθ*. The component of gravitational force perpendicular to the incline is mgcosθ, which equals the normal force N. So the frictional force is $f_s = \mu_s mgcos\,\theta$ (opposite to *mgsinθ)*. When the body just begin to move , the total force acting on the body is zero

$$mgsin\,\theta - \mu_s mgcos\,\theta = 0 \quad \text{which gives} \quad \mu_s = \tan\theta$$

Step-by-Step Procedure:

1. **Set up the inclined plane:**
   - Place the block or object on the inclined plane.
   - Ensure the inclined plane has a smooth, adjustable surface.
2. **Gradually raise the incline:**
   - Slowly raise one end of the inclined plane to increase the angle of inclination.
   - Observe the block carefully as the incline increases.
3. **Identify the point of sliding:**
   - Stop adjusting the incline as soon as the block **just starts to slide**.
   - At this point, the static friction is overcome by the gravitational component pulling the block down.
4. **Measure the distances:**
   - Measure the **vertical height** (denoted as h) from the base of the inclined plane to the point where the plane touches the raised end.

- Measure the **horizontal distance** (denoted as d) from the base of the inclined plane to the point where the block started sliding.

These two distances form the sides of a right triangle, where:

- h is the vertical leg (height).
- d is the horizontal leg (base).

- Then find tan θ.

Object	Trial no	x (change this)	y	Tanθ = y/x
	1. 2. 3.			

-

Result: The coefficient of static friction of different objects on wood is calculated and tabulated

4. Acceleration of a Freely Falling Body

Aim: Using the smartphone acoustic stopwatch determine the duration of a free fall and hence determine the value of g.

Apparatus: Smartphone(acoustic stopwatch, Phyphox app)**,** steel ball or marble ball,scale.

Theory:

Acceleration due to gravity: Acceleration due to gravity, often denoted by *g*, is the acceleration experienced by an object due to the gravitational force exerted by a massive body, like the Earth. This acceleration is directed towards the center of the massive body and is a fundamental parameter in physics, influencing the motion of objects near the surface of the Earth or any other celestial body**.**

The standard value of acceleration due to gravity on the surface of the Earth is approximately 9.81 m/S^2. This means that, in the absence of air resistance, an object in free fall near the Earth's surface will accelerate downwards at a rate of 9.81 m/S^2. This value can vary slightly depending on altitude, latitude, and local geological structures.

We have the equation of motion $S = ut + \frac{1}{2} at^2$

For a free fall from height h, u = 0 and we may modify above equation as

$$h = \frac{1}{2} at^2$$

where 't' is the time taken for free fall from height to ground. Here 'a' is 'g' and $g = \frac{2h}{t^2}$.

Plot a graph of *2h Vs t^2 and the* slope of the curve will give 2h / t^2.

Procedure

Place a steel ball at the end of a ruler. Measure the height, h of the scale from the bottom.

Open the Acoustic stop watch from the Phyphox app (Phyphox -> Timers -> Acoustic Stopwatch). Set the Threshold value(the volume at which it reacts) and Minimum Delay(a value less than the time of fall. This is to prevent a single event sound to trigger the stop watch multiple times.) The start the stopwatch by tapping the play button.

Measure the duration of the free fall of the ball using smart phone (Phyphox -> Timers -> Acoustic stop watch.

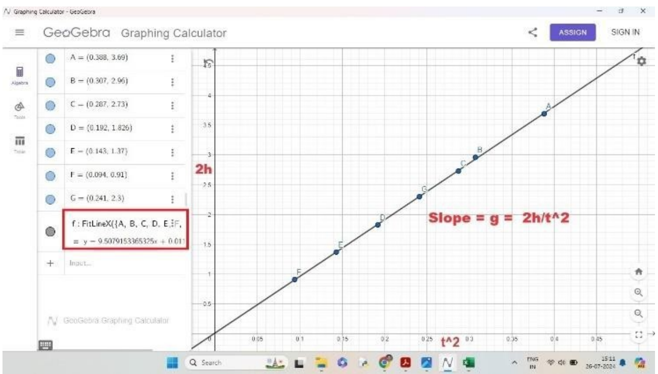
Place the steel ball at the end of ruler and drop it by hitting the ruler using a pen, screw driver, spanner etc. The sound that produced while hitting give the first trigger to start the stopwatch. The sound that produced when the ball touches the bottom(place a metal or plastic box at bottom for large sound) give the second trigger and the time between the events is recorded in the phone. Repeat the experiment two or three times.

s.no	Height h (m)	Time 1	Time 2	Mean t (s)	2h (m)	t^2	g = 2h/t^2
1							
2							
3							
4							
5							
6							
7							
8							

Mean g=.............

$$Percentage\,error=\frac{9.8-g}{9.8}\times 100$$

Plot a graph of 2h vs. t^2 using GeoGbra or any other software and from the slope determine value of g. (FitLine function in GeoGebra can be used to get the slope)



Result: 1) Accelaration due to gravity from observation:-------------

2) From Geogebra Plot=------------------------------

5. Analysis of Bouncing Balls to Determine Gravitational Acceleration and Coefficient of Restitution.

Aim:

To calculate acceleration due to gravity and coefficient of restitution, e using Phyphox app

Apparatus:

Ball (Basketball, Tennis ball, Golf ball etc.), Mobile phone with phyphox app

Principle:

Acceleration due to gravity: Acceleration due to gravity, often denoted by g, is the acceleration experienced by an object due to the gravitational force exerted by a massive body, like the Earth. This acceleration is directed towards the center of the massive body and is a fundamental parameter in physics, influencing the motion of objects near the surface of the Earth or any other celestial body**.**

The standard value of acceleration due to gravity on the surface of the Earth is approximately 9.81 m/S^2. This means that, in the absence of air resistance, an object in free fall near the Earth's surface will accelerate downwards at a rate of 9.81 m/S^2. This value can vary slightly depending on altitude, latitude, and local geological structures.

We have the equation of motion $S = ut + \frac{1}{2}at^2$

For a free fall from height h, u = 0 and we may modify above equation as

$$h = \frac{1}{2}at^2$$

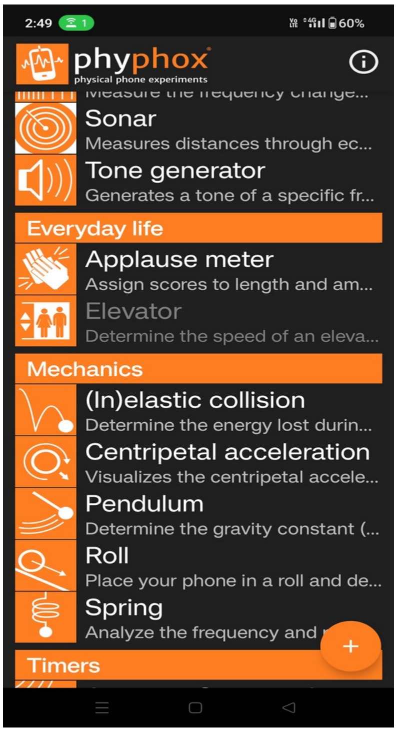
where 't' is the time taken for free fall from height to ground.

Coefficient of restitution (COR, also denoted by e): It is the ratio of the relative velocity of separation after collision (difference in velocities of two bodies colliding each other, here they are ball and the ground) to the relative velocity of approach before collision. Here V_{1i} and V_{1f} denotes initial and velocity of the first body (Here ground). V_{2i} and V_{2f} denotes initial and velocity of the second body (ball).

$$\frac{Relative\ velocity\ of\ separation\ after\ collision}{Relative\ velocity\ of\ approach\ before\ collision}=\frac{V_{2f}-V_{1f}}{V_{2i}-V_{1i}}$$. As the ground is at rest before and after collision $$e=\frac{Relative\ velocity\ of\ separation\ after\ collision}{Relative\ velocity\ of\ approach\ before\ collision}=\frac{V_{2f}}{V_{2i}}$$

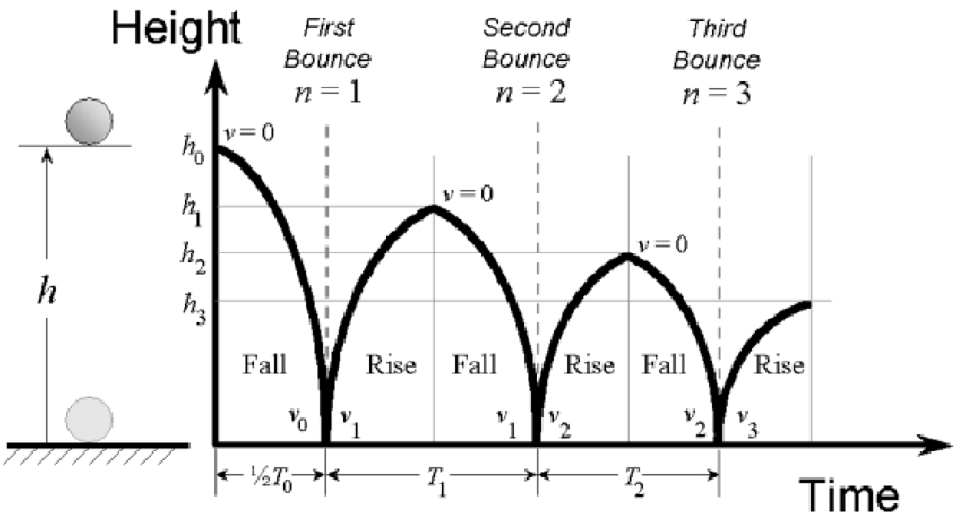
For an elastic collision, e = 1, because difference in velocities before and after collision is same. For a totally inelastic collision e = 0, since two bodies stick together after collision and velocity difference is zero. For a collision that is inelastic, but not totally inelastic, e will have some value in between these two extremes.

Procedure:



Step 1: Install Phyphox app in your mobile phone. Choose the path 'elastic collision' to determine the hight of bouncing ball and the taken between two bouncing, for each bounce. (select threshold as 0.5 and minimum delay 0.2 s)

Step 2: The data obtained is taken as the height of first bounce h_1, second bounce h_2, third bounce h_3 etc. The time recorded in app is T_1, T_2, T_3 etc. So the time taken for each fall is $T_1/2$, $T_2/2$, $T_3/2$ etc



Trial no	h	T	$g=\frac{2h}{(T/2)^2}$
1	h_1	T_1	
2	h_2	T_2	
3	h_3	T_3	
4	h_4	T_4	
5	h_5	T_5	

Mean g = ---------------m/s^2

Step 3: To find Coefficient of restitution, find the velocity of separation and velocity of approach of the ball.

For first fall , relative velocity of approach is $\frac{h_1}{T_1/2}$ and velocity of separation after collision is $\frac{h_2}{T_2/2}$

Repeat the same for 6 bounces.

Observations: To find coefficient of restitution

Height(1)	Time(1)	Height(2)	Time(2)	Height(1)/Time(1) x	Height(2)/Time(2) y	e=y/x
h_1	**$T_1/2$**	h_2	**$T_2/2$**			
h_2	**$T_2/2$**	h_3	**$T_3/2$**			
h_3	**$T_3/2$**	h_4	**$T_4/2$**			
h_4	**$T_4/2$**	h_5	**$T_5/2$**			
h_5	**$T_5/2$**	h_6	**$T_6/2$**			

Mean e = ------------

RESULT:

1. **The acceleration due to gravity at the place is = _______________________**

2. **The Coefficient of restitution is =_____________________________**

6. The Nearly Parabolic Trajectories of a Bouncing Ball

Aim:

To calculate acceleration due to gravity and coefficient of restitution, e using Tracker video analysis and modelling tool.

Apparatus:

Ball (Basketball, Tennis ball, Golf ball etc.), meter scale, Mobile phone, PC/ laptop installed with Tracker software.)

Principle:

Acceleration due to gravity: Acceleration due to gravity, often denoted by g, is the acceleration experienced by an object due to the gravitational force exerted by a massive body, like the Earth. This acceleration is directed towards the center of the massive body and is a fundamental parameter in physics, influencing the motion of objects near the surface of the Earth or any other celestial body**.**

The standard value of acceleration due to gravity on the surface of the Earth is approximately 9.81 m/S^2. This means that, in the absence of air resistance, an object in free fall near the Earth's surface will accelerate downwards at a rate of 9.81 m/S^2. This value can vary slightly depending on altitude, latitude, and local geological structures.

We have the equation of motion $S = ut + \frac{1}{2}at^2$

For a free fall form height h, u = 0 and we may modify above equation as

$$h = \frac{1}{2}at^2$$

where 't' is the time taken for free fall from height to ground.

Coefficient of restitution (COR, also denoted by e): It is the ratio of the relative velocity of separation after collision (difference in velocities of two bodies colliding each other, here they are ball and the ground) to the relative velocity of approach before collision.

Here V_{1i} and V_{1f} denotes initial and velocity of the first body (Here ground). V_{2i} and V_{2f} denotes initial and velocity of the second body (ball).

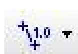
$$\frac{Relative\ velocity\ of\ separation\ after\ collision}{Relative\ velocity\ of\ approach\ before collision} = \frac{V_{2f} - V_{1f}}{V_{2i} - V_{1i}}$$. As the ground is at rest before and after collision $$e = \frac{Relative\ velocity\ of\ separation\ after\ collision}{Relative\ velocity\ of\ approach\ before collision} = \frac{V_{2f}}{V_{2i}}$$

For an elastic collision, e = 1, because difference in velocities before and after collision is same. For a totally inelastic collision e = 0, since two bodies stick together after collision and velocity difference is zero. For a collision that is inelastic, but not totally inelastic, e will have some value in between these two extremes.

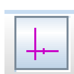
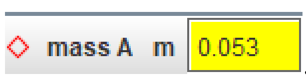
Procedure:

Step 1: Record the bouncing ball experiment using the mobile phone with meter scale in background (White background, Dark colored ball preferred). Ensure that at least SIX bounces are clearly recorded.

Step 2: Upload the video in tracker video analysis tool.

Step 3: From 

select New->Calibration stick and drag and place to end points of the reference stick.

Step 4: From  set the coordinate axis at the starting point of the ball. Define point mass. Track->New->Point Mass. Rename if needed. Give the mass of the ball 

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Step 5: Use tracker tool to mark the object (Shift+ mouse click) and then click each point for manual track or (ctrl+Shift) and spot the object and click search and match the figure by auto search

Step 6: Use auto tracker tool and let the program track the object in each frame.

Step 7: Obtain the Time- Distance (t-y) columns and corresponding graph as in Fig. 1.

Step 8: First free fall is from A to B . The distance travelled is h_1 . It is obtained by taking difference of 'y' at A and B .The time taken for the fall is obtained by taking difference of ‘t’ at A and B (by clicking mouse). Second fall from C to D. Distance and time taken as before

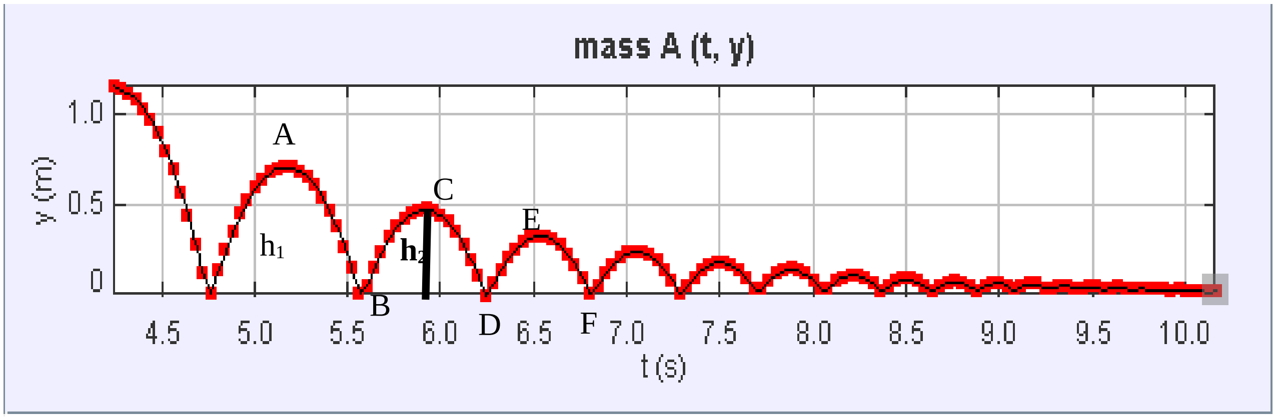


Fig. 1.1 Time distance graph of bouncing ball

Step 8: Use the data from table or the graph to find the time taken between successive bounces and distance travelled during each bounces as in Fig. 2.

Step 9: Use equation to find acceleration due to gravity. Repeat for 6 bounces.

Observations: To find acceleration due to gravity

Trial no	**h**	**t**	$g=\frac{2h}{t^2}$
1	h_1	$\mathbf{t_B - t_A}$	
2	h_2	$\mathbf{t_D - t_C}$	
3	h_3	$\mathbf{t_F - t_E}$	
4	h_4		
5	h_5		

Step 10: To find Coefficient of restitution. (Find the velocity for each bounces from distance-time graph). For first fall , relative velocity of approach is $\frac{h_1}{t_B - t_A}$ and velocity of separation after collision is $\frac{h_2}{t_D - t_C}$ Repeat the same for 6 bounces.

Observations: To find coefficient of restitution

Height(1)	Time(1)	Height(2)	Time(2)	Height(1)/Time(1) x	Height(2)/Time(2) y	e=y/x
h_1	$t_B - t_A$	h_2	$t_D - t_C$			
h_2	$t_D - t_C$	h_3	$t_F - t_E$			
h_3	$t_F - t_E$	h_4	$t_H - t_G$			

Mean e = ------------

RESULT:

3. **The acceleration due to gravity at the place is = _______________**

4. The Coefficient of restitution is =__________________________

7. Analysis of Air Resistance and Terminal Speed to Determine the Drag Coefficient

Aim:

Record the motion of a light weight paper cup and analyze it with Tracker tool to Plot acceleration, velocity, and position with time graph and to determine the Drag Coefficient.

Apparatus:

Paper cups, meter scale, Mobile phone, PC/ laptop installed with Tracker software.

Principle:

The resistance force exerted by a fluid is known as drag force; it always acts opposite to the direction of an object's motion when submerged in a fluid. Hence, drag force can be described as the force that opposes or resists the motion of a body within a fluid. The fundamental nature of drag force is to act in the opposite direction of the flow velocity. An example of drag force is air resistance, which always opposes the terminal speed of an object falling from a height. The value of drag force is directly proportional to the fluid's density, the square of the velocity, the cross- sectional area, and the drag coefficient.

When an object moves through a fluid, the coefficient used to compute its resistance is known as the drag coefficient, denoted by $\mathbf{C_d}$. The drag coefficient is dimensionless and is useful for calculating aerodynamic drag and the effects of shape, inclination, and flow conditions in aerodynamics. Generally, blunt and bulky objects have a high drag coefficient, while streamlined objects have a lower drag coefficient. To determine the aerodynamic or hydrodynamic force on an object, drag coefficients are used, as described by the drag equation below:Two forces acting on a falling body (Paper cup) are $F_{gravitation}$ and F_{Drag}

$$F_{gravitation} = mg$$

$$F_{Drag} = C_d V$$

At terminal velocity $F_{gravitation} = F_{Drag}$

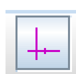
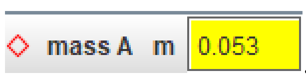
$$mg = C_d V$$

$$C_d = \frac{mg}{V}$$

Step 1: Record the paper cup fall using the mobile phone with scale in background (White background, Dark colored cup preferred).

Step 2: Upload the video in tracker video analysis tool.

Step 3: From  select New->Calibration stick and drag and place to end points of the reference stick.

Step 4: From  set the coordinate axis at the starting point of the ball. Define point mass. Track->New->Point Mass. Rename if needed. Give the mass of the ball 

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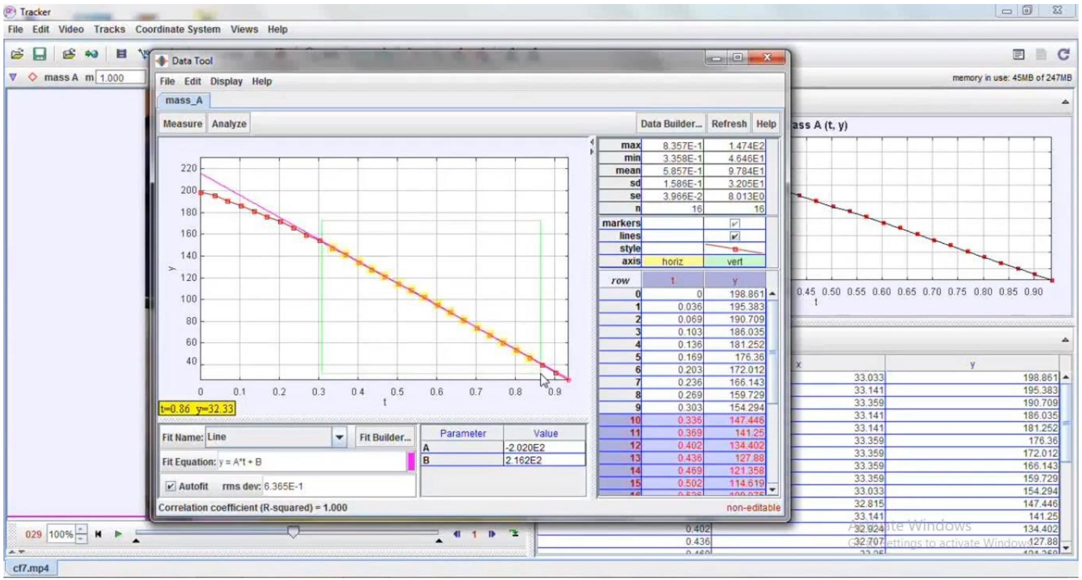
Step 5: Use tracker tool to mark the object (Shift+ mouse click) and then click each point for manual track or (ctrl+Shift) and spot the object and click search and match the figure by auto search

Step 6: Use auto tracker tool and let the program track the object in each frame.
Step 7: Plot the position-Time graph and (Fit it to straight line by clicking analyze and find the slope to get the terminal velocity-Linear part)

Step 8: Use the terminal velocity to find drag coefficient
Step 9: Repeat the experiment using stacking the paper cups and increasing the weight.



Observation:

Sl no	Number of Cups	Mass	Terminal velocity(slope of curve) V	Drag coefficient $C_d = \frac{mg}{V}$

Result:

1. **The position- Time graph for falling paper cup is plotted and terminal velocity is found.**
2. **The average drag coefficient = ____________________________**