1. BIFILAR PENDULUM

**Aim**: To determine the moment of inertia of a bifilar pendulum and verify the perpendicular axes theorem.

**Apparatus**: A rectangular metal or wooden block having a pair of chucks or hooks on each of its three planes (bifilar pendulum). Two retort stands, suitable clamps for suspending the block, meter scale, stop watch, vernier calipers and twine thread.

**Description**: The bifilar pendulum consists of a heavy and uniform rectangular metallic plate. Each face of the pendulum is provided with a pair of holes, symmetrically situated on either side of the centre of the face. The body is suspended from a rigid support MN by means of a equal and torsion less string. When the body is twisted through a small angle in the horizontal plane and released, it executes simple angular oscillations about the vertical axis passing through its centre of gravity. The bifilar pendulum can be suspended in any desired position (vertical or horizontal) and the distance between the strings can be altered by means of screws provided at the rigid support.

**Perpendicular axes theorem**: The Moment of Inertia of a plane laminar body about an axis perpendicular to the plane of the body is equal to the sum of moments of inertia of the body about two mutually perpendicular axes lying in the plane of the body.

**Procedure**: Suspend the rectangular block or (bifilar pendulum) from plane (a b) by two equal length of threads from the chucks or hooks attached to a horizontal rigid support. a, b and c denote the length, breadth and thickness of the block respectively.

Arrange the plane (a b) horizontal. Attach a pin to one edge of the block. Keep a vertical pointer in line with the pin when the block is at rest. Turn the block in its own plane through a small angle about the vertical axis, through its centre of gravity. Then release the block. It executes simple harmonic motion. Record the time twice for 20 oscillations. Count the oscillations with reference to the vertical pointer. Hence obtain the period of oscillation (T).

Measure the distance between the points of oscillations 2d₁ and measure the distance between the points of suspension as 2d₂. Measure the perpendicular distance (h) between the planes containing the lower and upper ends of the threads. Record the readings in the tabular form.

Similarly, suspend the block horizontally on other two planes (ac) and (bc). In each case note the time for 20 oscillations twice, setting the block in motion and measure 2d₁, 2d₂ and h. Determine the mass (M) of the block.

Determine the moment of inertia of the bifilar pendulum about the three axes for each suspension by using the formula
\[ I = MgT^2 d_1 d_2 / 4 \pi^2 h \text{ gm} \cdot \text{cm}^2 \]

Where \( I \) is moment of inertia of the rectangular block about an axis through its centre of gravity, perpendicular to the horizontal plane. Repeat the experiment with various values of \( 2d_2 \) and \( h \).

**Verification**: Verify the practical values of moment of inertia about the three axes by using the theoretical formulae.

About the axis perpendicular to plane (ab), \( I_1 = M(a^2 + b^2) / 12 = \)

About the axis perpendicular to plane (bc), \( I_2 = M(b^2 + c^2) / 12 = \)

About the axis perpendicular to plane (ca), \( I_3 = M(c^2 + a^2) / 12 = \)

Measure the lengths (a), breadth (b) with scale and thickness (c) of the block with the vernier calipers.

If the block is very thin, the theorem of perpendicular axes can be verified by using the relation

\[ I_1 = I_2 + I_3. \]

**Precautions**:

1. Suspend the block symmetrically.

2. The body should vibrate about a vertical axis.

**Result**:

<table>
<thead>
<tr>
<th></th>
<th>( I_2 )</th>
<th>( I_3 )</th>
<th>( I_2 + I_3 )</th>
<th>( I_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical</td>
<td></td>
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<tr>
<td>Observed</td>
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</tbody>
</table>

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Name:
Roll No:
**Observations:**
- Mass of the block \( M \) gms \( = \) 
- Average length of the block \( a \) cm \( = \) 
- Average breadth of the block \( b \) cm \( = \)

**Thickness of the block:** (using vernier calipers)

<table>
<thead>
<tr>
<th>S.No</th>
<th>M.S.R ( a ) cm</th>
<th>V.C</th>
<th>( B = (V.C \times l.c) )</th>
<th>Total i.e. Thickness ( C = (a + b) ) cm</th>
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</table>

Average thickness of the block \( c \) cm \( = \)

<table>
<thead>
<tr>
<th>Description</th>
<th>S.No</th>
<th>Height ‘h’ cm</th>
<th>Time for 20 oscillations</th>
<th>Time period ( T = t/20 ) sec</th>
<th>( I = M g T^2 \frac{d_1 d_2}{4 \pi^2 h} ) gm-cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane ( a \ b )</td>
<td>1</td>
<td>( h_1 )</td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Average ‘t’ sec</td>
</tr>
<tr>
<td>2 ( d_1= )</td>
<td></td>
<td></td>
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<tr>
<td>2 ( d_2= )</td>
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<tr>
<td>2 ( d_3= )</td>
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<td></td>
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<tr>
<td>Plane ( b \ c )</td>
<td>2</td>
<td>( h_1 )</td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Average ‘t’ sec</td>
</tr>
<tr>
<td>2 ( d_1= )</td>
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<td>2 ( d_2= )</td>
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<td>2 ( d_3= )</td>
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<tr>
<td>Plane ( a \ c )</td>
<td>3</td>
<td>( h_1 )</td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Average ‘t’ sec</td>
</tr>
<tr>
<td>2 ( d_1= )</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>2 ( d_2= )</td>
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<td></td>
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<tr>
<td>2 ( d_3= )</td>
<td></td>
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</tr>
</tbody>
</table>

Average \( I_1 = \)

Average \( I_2 = \)

Average \( I_3 = \)
Date:

2. Spiral spring (Rigidity modulus)

η of a flat spiral spring (Dynamic method)

Aim: To determine the rigidity modulus of the material of the wire of the spring.

Apparatus: A flat spiral spring, a uniform rod (either of rectangular cross-section or of circular cross-section), a Dead weight, stop-watch, vernier calipers, screw-gauge and a scale.

Description: A flat spiral spring is made of closely wound wire whose radius is small compared to the radius of the spring. Such a spring is made by winding the wire on a wooden cylinder of suitable diameter. The ends of the spring are bent twice at right angles so that the free ends OO₁ are along the axis.

Theory:

The ratio of the tangential stress to the corresponding shearing strain, within the elastic limits, is called the modulus of rigidity. Tangential stress is equal to the tangential force applied per unit area at equilibrium.

Shearing strain is the angle in radians through which the plane of the surface is twisted (or) turned.

The moment of the twisting couple on the wire is given by

\[ C = \frac{\pi \theta r^4}{2l} \]

where \( \eta \) - is the modulus of rigidity
r - is the radius of the wire
\( \theta \) - is the angle of twist
l - is the length of the wire

If the wire is in the form of a spring of N turns and radius R then its length

\[ l = 2\pi RN \]
When a mass M is suspended at one end of the spring it extends by twisting the wire. If R is the radius of the spring and x is the displacement of the spring downwards then the twist of the wire is given by

\[ \theta = \frac{x}{R} \quad \text{or} \quad x = \frac{\theta}{R} \]

\[ \frac{4R^2N\eta r^4}{\eta r^4} \]  \quad (3) (by using eqn 1 and 2)

If the restoring force on the mass M due to the spring is f then couple acting on the wire is given by

\[ C = fR \quad \text{or} \quad f = \frac{c r^4 x}{4R^2N} \]

\[ \frac{\eta r^4 x}{4R^2N} \]  \quad (4)

since force can be represented as M \( \frac{d^2x}{dt^2} \)

eqn (4) becomes \[ M \frac{d^2x}{dt^2} = -\frac{\eta r^4 x}{4R^2N} \]  \quad (5)

Comparing the equation (5) with the differential equation of a simple harmonic oscillator

\[ M \frac{d^2x}{dt^2} = -Kx \]

The time period of the oscillating spring is given by

\[ T = 2\pi \sqrt{\frac{M}{K}} = 2\pi \sqrt{\frac{4MR^3N}{\eta r^4}} \]

solving for \( \eta \) gives

\[ \eta = \frac{16\pi^2MR^3N}{r^4T^2} \]  \quad (6)

If the mass m of the spring is taken into account eqn (6) becomes

\[ \frac{16\pi^2R^3N(M+m/3)}{T^2r^4} \text{ dynes/sq cm} \]

Where R – Radius of the spring
\( \eta \) – is the modulus of rigidity
r – is the radius of the wire
N – no. of turns of the spring
M – mass attached + mass of the dead weight
m – mass of the spring + mass of the dead weight
T – Time period
If a graph is drawn with $M$ on x-axis and $T^2$ on the Y-axis a straight line is obtained. The intercept on the negative x-axis gives the value of $m/3$. Modulus of rigidity may also be calculated without finding the value of $m/3$ by using the formula.

$$\eta = \frac{16\pi^2 R^3 N (M_2-M_1)}{r^4 \left( T_2^2 - T_1^2 \right)} \text{ dynes/cm}^2$$

**Procedure:**

(i) **Determination of rigidity modulus(\(\eta\)):-**

1. The spring is clamped vertically and firmly at one end. A mass $M$ is attached firmly to lower end.
2. The mass ($M$) is pulled down a little and released.
3. It executes oscillations up and down along the axis of the spring.
   - Time for 20 oscillations is taken twice and mean is noted. The time period ($T$) is tabulated.
4. The experiment is repeated for various loads and the corresponding time periods are noted. The observations are tabulated.

The mass ($m$) of the spring + dead weight is determined accurately. The no. of turns of the spring($N$) is counted. The diameter ($2R$) of the spring is determined using vernier calipers from which radius($R$) of the spring is calculated. The radius of the wire ($r$) is measured with a screw gauge very accurately. Draw a graph between load $M$ (including the dead weight) and $T^2$. The graph is a straight line cutting the negative X-axis. The intercept on the negative X-axis gives $m/3$

Substituting the above values the rigidity modulus of the spring is calculated from the formula.

$$\eta = \frac{16\pi^2 R^3 N (M+m/3)}{r^4 T^2} \text{ dynes/cm}^2$$

**Precautions:**

1. Spring should be clamped firmly at its upper end.
2. The mass should be attached firmly to the spring at the lower end.
3. The radius of the wire($r$) should be measured accurately as it occurs in fourth power.

**Result:**

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Observations: For rigidity modulus:

1. Number of turns of the spring N =

2. Mass of the spring along with dead weight m =

3. Mass of the dead weight m₁ =

4. Radius of the spring R = cm

Least Count of the vernier = \frac{1 \text{ main scale division}}{\text{No. of divisions on vernier}} = cm

Table: diameter of the spring using vernier calipers:

<table>
<thead>
<tr>
<th>S.No</th>
<th>M.S.R cm</th>
<th>V.C cm</th>
<th>V.C X L.C cm</th>
<th>Diameter of the spring D = M.S.R+(V.C X L.C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
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<td>4.</td>
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</tbody>
</table>

Average \ D = cm.

Radius of the spring R = D/2 = cm.

5. Table: Radius of the wire

Least Count = \frac{\text{Pitch of the screw}}{\text{No. of head scale divisions}}

Pitch of the screw = distance travelled in 5 rotations / 5 = mm
Diameter of the wire: error: correction:

<table>
<thead>
<tr>
<th>S.No</th>
<th>P.S.R mm</th>
<th>H.S.R</th>
<th>C.H.S.R mm</th>
<th>C.H.S.RX.L.C</th>
<th>Diameter of the wire d = P.S.R+(C.H.S.RX.L.C)mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
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<td>4.</td>
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</table>

Average d = mm = cm.

Radius of the wire r = d/2 = mm = cm

6. Determination of Rigidity modulus(\(\eta\))=

**Observation table for Time Period of oscillation :T**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Load M gm</th>
<th>Time for 20 oscillations (sec)</th>
<th>Time period T= t/20 sec</th>
<th>(T^2)</th>
<th>(M+m/3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hanger weight + dead weight</td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Mean ‘t’</td>
<td></td>
</tr>
</tbody>
</table>

Average: \(\frac{M+m/3}{T^2}\)

From the graph 1) \(m/3 = \)

2) \(\eta = 16\pi^2R^3N (M_2-M_1)\)

\(\frac{r^4}{T_2^2-T_1^2}\)

3) \(\eta = \frac{16\pi^2R^3N (M + m/3)}{r^4} \) dynes/cm²

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**3. Spiral spring (Young’s modulus)**

**Aim:** To determine the Young’s modulus of the material of the wire of the spring using dynamic method.

**Apparatus:** A flat spiral spring, a uniform rod (either of rectangular cross-section or of circular cross section, two small weights, stop-watch, vernier calipers, screw-gauge and a scale.

**Description & Theory:** Same as in rigidity modulus experiment.

**Procedure:**

**Method for determining Y:**

1. The spring is clamped vertically and firmly at one end. A screw rod is attached to the lower end of the spring, firmly so that the axis of the spring passes through C.G of the rod. On either side of the rod there are two equal masses of mass ‘m’ each. They are placed symmetrically on either side of the rod at equal distances say (d1).

2. The rod is then turned through a small angle in the horizontal plane and released. When it is executing oscillations, the time for 20 oscillations is noted twice and the mean t is taken.

3. From, the above time period T is calculated.

4. The masses are then moved to distance d2 and the time period T2 is noted again as above.

5. The mass ‘m0’ of each mass is determined and average mass ‘m0’ is calculated. Knowing the above values ‘Y’ is calculated from the formula.

6. The above procedure is repeated for six values of d.

\[
Y = \frac{64\pi^2NRm_0 (d_2^2-d_1^2)}{T^4(T_2^2-T_1^2)} \quad \text{(3)}
\]

Knowing η and Y from eqn (1) and (2) Poisson’s ratio is calculated using the formula

\[
\sigma = \frac{\text{Y} - 1}{2n} \quad \text{(4)}
\]

**Figure:**

![Diagram of the experiment setup showing the spiral spring, masses, and rod.]
Precautions:

1. Spring should be clamped firmly at its upper end.
2. The rod should be firmly fixed to the lower end by means of the screw and the rod must be horizontal.
3. The radius of the wire(r) should be measured accurately as it occurs in fourth power.

Result:

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**Determination of Young’s Modulus (Y):**

Radius of the spring (R) = cm  
No. of turns of the spring (N) =  
Radius of the wire (r) = cm  
Average mass of the cylindrical weights = m₀ =  

Least Count of the vernier = \( \frac{1 \text{ main scale division}}{\text{No. of divisions on vernier}} \) = cm

**Table: diameter of the spring using vernier calipers:**

<table>
<thead>
<tr>
<th>S.No</th>
<th>M.S.R cm</th>
<th>V.C cm</th>
<th>V.C X L.C cm</th>
<th>Diameter of the spring ( D = M.S.R + (V.C \times L.C) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
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<td>3.</td>
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<tr>
<td>4.</td>
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</tr>
</tbody>
</table>

Average \( D = \) cm.

Radius of the spring \( R = \frac{D}{2} = \) cm.
Table: Radius of the wire

Least Count = Pitch of the screw
No. of head scale divisions

Pitch of the screw = distance traveled in 5 rotations / 5 = mm

Diameter of the wire: error: correction:

<table>
<thead>
<tr>
<th>S.No</th>
<th>P.S.R mm</th>
<th>H.S.R</th>
<th>C.H.S.R mm</th>
<th>C.H.S.R.XL.C mm</th>
<th>Diameter of the wire d = P.S.R+(C.H.S.R.XL.C)mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
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</tbody>
</table>

Average d = mm = cm.

Radius of the wire r = d/2 = mm = cm

Observation table for time period of oscillation T:

<table>
<thead>
<tr>
<th>s.no</th>
<th>Distance (d) cm</th>
<th>Time for 20 oscillations</th>
<th>Time period</th>
<th>T² sec²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Mean sec</td>
</tr>
<tr>
<td>1.</td>
<td>4 d₁</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>5 d₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>6 d₁</td>
<td></td>
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<tr>
<td>4.</td>
<td>7 d₂</td>
<td></td>
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<tr>
<td>5.</td>
<td>8 d₁</td>
<td></td>
<td></td>
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<tr>
<td>6.</td>
<td>9 d₂</td>
<td></td>
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</tbody>
</table>

Using the above values in the formula

\[ Y = \frac{64\pi^2 NRm_0 (d_2^2 - d_1^2)}{r^4 \left( T_2^2 - T_1^2 \right)} \]

the value of young’s modulus is determined.
Spiral Spring

1. What is young’s Modulus? On what factors does it depend? what are its units in C.G.S system?
2. What is elastic limit?
3. How do you measure the strain in this case?
4. What factors control the periodic time of the torsional oscillations of the spiral spring?
5. Why this method is called a dynamic method?
6. What is meant by the restoring torque per unit time? What factors control this quantity?
7. What is a Spiral Spring?
8. What types of springs do you know?
9. What is effective mass of a spring?
10. How does the restoring force, change with length and radius of spiral spring?
11. How the knowledge of restoring force per unit extension is of practical use?
12. What is Rigidity modulus? On what factors does it depend? What are its units in C.G.S system?
4. FLY WHEEL

**Aim:** To determine the moment of inertia of a flywheel about its axis of rotation.

**Apparatus:** Fly wheel, metre-scale, vernier callipers, stop watch, set of weights, weight hanger and twine thread.

**Formula:** Moment of Inertia $I = \frac{mn_2}{n_1+n_2} \left( \frac{2gh - r^2}{\omega^2} \right) \text{gm.cm}^2$

where $\omega = \frac{4\pi n_2}{t}$

Where $I =$ moment of inertia of the flywheel about its axis of rotation.

$n_1 =$ no. of revolutions made by the wheel before the mass just reaches the ground or number of turns of the thread on the axle.

$n_2 =$ number of revolutions made by the wheel from the instant the string is detached from the axle to the instant the wheel come to rest.

$t =$ time taken by the wheel in making $n_2$ revolutions.

$g =$ acceleration due to gravity (980 cm/sec$^2$).

$r =$ radius of the axle .

$\omega =$ angular velocity of the wheel $= \frac{4\pi n_2}{t}$

$m =$ mass attached to the string.

$h =$ distance between the ground and bottom of the mass.

**Description:** A flywheel is a large heavy wheel, with a long cylindrical axle. The centre of gravity lies on its axis of rotation so that when it is mounted over ball bearings, it comes to rest in any desired position. To increase the moment of inertia, it is usually made thick at the rim as shown in fig. To count the no. of revolutions made by wheel, a line is marked on the circumference. A string is wound on the axle, attached to the peg p and carries a mass m.

**Principle:** Suppose the wheel is accelerated from rest by a weight attached to one end of a thin and in-extensible string which is wound evenly round the axle of the flywheel. Let its other end be tied to a small peg in the axle. Further, it is so arranged that the string becomes detached when the weight has fallen through a suitable distance usually to the floor and the wheel is allowed to come to rest under the action of the frictional couple in the bearings.(The length of the string is adjusted so that when the loop of the string is tied to the peg in the axle, the bottom of the weight attached to the string just touches the ground.) The wheel is now rotated so that the string makes a required number of turns on the axle.
Let $m\rightarrow$ be the mass of the suspended weight in gm

$h\rightarrow$ distance between the ground and the bottom of the mass.

$v\rightarrow$ cm/sec, the linear velocity of the axle

$\omega\rightarrow$ radian/sec, the angular velocity of the wheel when the string becomes detached.

$I\rightarrow$ gm-cm$^2$ the moment of inertia of the wheel

$r\rightarrow$ the radius of the axle in cm

$(n_2\rightarrow$ the no. of revolution during the descent of mass $m$) after the loop falls down

$f\rightarrow$ the work done per revolution against frictional forces supposed to be constant.

The potential energy ‘mgh’ lost by the falling mass $m$ is used up in producing.

(i) K.E of rotation, $\frac{1}{2} I\omega^2$ of the flywheel.

(ii) K.E of translation, $\frac{1}{2} mv^2$ of the falling mass and

(iii) In doing work against friction at the bearings.

Then by the principle of conservation of energy we have

$$mgh = \frac{1}{2} I\omega^2 + \frac{1}{2} mv^2 + nf$$

If, after the mass has been detached from the axle the wheel makes $N$ rotations before coming to rest and takes $t$ seconds to do so, then assuming that the angular velocity decreases at a uniform rate till the wheel comes to rest, the average value of angular velocity during this period $= \omega/2$.

Obviously, then

$$\omega = \frac{2\Pi n_2}{t}$$

(or) $$\omega = \frac{4\Pi n_2}{t}$$

Since the energy possessed by the rotating wheel, $\frac{1}{2} I\omega^2$, is used up in doing work against friction in $n_2$ rotations. We have

$$n_2 X f = \frac{1}{2} I\omega^2$$

$$f = \frac{I\omega^2}{2n_2}$$

putting this value of $f$ and that of $v(=r\omega)$ in eqn(1)
we have \( mgh = \frac{1}{2} I \omega^2 + \frac{1}{2} mr^2 \omega^2 + n \left( \frac{1}{2} I \omega^2 \right) \frac{n_2}{2} \)

\( = \frac{1}{2} I \omega^2 \left( 1 + \frac{n_1}{n_2} \right) + \frac{1}{2} mr^2 \omega^2 \)

(or) \( \frac{1}{2} I \omega^2 \left( 1 + \frac{n_1}{n_2} \right) = mgh - \frac{1}{2} mr^2 \omega^2 \frac{n_2}{n_2} \)

\[ I = \frac{mgh}{\omega^2 \left( 1 + \frac{n_1}{n_2} \right)} - \frac{mr^2}{\frac{1}{n_2} \left( 1 + \frac{n_1}{n_2} \right) \frac{n_2}{n_2}} \]

\[ = 2 \left( \frac{mgh}{\omega^2} - mr^2 \right) \frac{1 + \frac{n_1}{n_2}}{n_2} \]

\[ = m \left( \frac{2gh}{\omega^2} - r^2 \right) \frac{1 + \frac{n_1}{n_2}}{n_2} \]

where \( \omega = \frac{4\Pi n_2}{t} \) by eqn (2)

Procedure:

1. Attach a mass \( m \) (about 400gm) to one end of a thin thread and a loop is made at the other end which is barked to the peg.
2. The thread is wrapped evenly round the axle of the wheel.
3. Allow the mass to descend slowly and count the revolution \( n_1 \) during descent.
4. When the thread has unwound itself and detached from the axle after \( n_1 \) turns, start the stop watch. Count the number of revolution \( n_2 \) before the flywheel comes to rest and stop the stop watch. Thus \( n_2 \) and \( t \) are known.
5. With the help of vernier callipers, measure the diameter of the axle at several points.
   Thus find \( r \).
6. Repeat the experiment with three different masses.
7. Calculate the value of \( I \) (moment of inertia) using the given formula.
Calculations:

\[ I = \frac{m}{n_1 + n_2} \left( \frac{ght^2 - n_2 r^2}{8\Pi^2 n_2} \right) \text{ gm-cm}^2 \]

Verification:

According to theoretical formula  
\[ I = \frac{MR^2}{2} \text{ gm-cm}^2 \]

where M is the mass of the wheel  
R is the radius of the wheel.

Circumference of the wheel  
\[ 2\Pi R = L \text{ cm} \]

\[ R = \frac{L}{2\Pi} = \text{ cm}. \]

Precautions:

i. There should be uniform winding on the axle  
ii. The string should be thin and strong to sustain mass attached to it  
iii. The loop should be loose  
iv. Friction should be made small by greasing the ball bearings.  
v. The diameter of the axle should be measured at various points.  
vi. Mass should fall freely.  
vii. Mass must start with zero velocity

Result:

Lecturer signature with date:
### Observations: Table 1:

| Load M gm | S.No | Height 'h’ cm | No. of turns of the thread n₁ | No. of revolutions n₂ | ‘t’ time for n₂ revolutions | I=m  
\[ \frac{gh}{n₁+n₂} - \frac{n₂r²}{8Πn₂} \] |
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<td>400gm</td>
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<td>trial-Ⅰ</td>
<td>trial-Ⅱ</td>
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<td>500gm</td>
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Average I= \( \text{gm.cm}^2 \)

**Table 2:** To determine the diameter ‘d’ of the axle: using vernier calipers

Diameter of the axle ‘d’ cm

Vernier Calipers Least Count= \( \text{cm} \).
Vernier least count = \( \frac{1 \text{ main scale division}}{\text{No. of divisions in the vernier scale}} \) = \( \frac{0.1}{10} \) = 0.01 cm

<table>
<thead>
<tr>
<th>S.no</th>
<th>M.S.R cm</th>
<th>V.C</th>
<th>V.C X L.C cm</th>
<th>M.S.R+(V.C X L.C) cm</th>
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</table>

Average diameter of the axle \( d = \) \( \text{cm} \).

Mean radius of the axle \( r= \frac{d}{2} \text{ cm} = \) \( \text{cm} \)
1. What is a fly wheel?
2. What is meant by moment of inertia of a body?
3. What are the units of moment of inertia (M.I) in C.G.S and M.K.S System?
4. What is a rigid body?
5. How can the M.I of the flywheel be increased?
6. How is the friction minimised in the flywheel?
7. Why the mass of a flywheel is concentrated at rim?
8. How and why does the flywheel start rotating?
9. Why the flywheel continues its revolutions even after the cord has slipped off the axle?
10. Why should a thin string be used in this experiment?
11. Why do you keep the loop slipped over the peg loose?
12. Where does the centre of gravity of the flywheel lie?
13. What is the purpose of finding \( n_2 \)?
14. Are ball bearings essential for holding the flywheel? How?
15. What will happen if the flywheel is made flatter?
16. What is the practical utility of a flywheel?
17. Does mobile engine also posses a flywheel?
18. we mention that the thread is to be wound around the axle without any overlap, what happens if there is an overlap?
19. Is the moment of inertia a scalar (or) a vector ? (or) is it something else?
20. what is the equation in rotatory motion analog us to \( F = ma \) in linear motion?
21. What is the relation between the moment inertia(I) and angular momentum(J)?
5. Torsional Pendulum

**Aim**: To determine the modulus of rigidity ($\eta$) of the material of the given wire by dynamic method (i.e., by torsional oscillations).

**Apparatus**: Torsional Pendulum (A circular wooden disc provided with a chuck at its centre), steel or brass wire, a chuck fixed to a stand or held in a rigid clamp, stop-watch, screw gauge.

**Description**: The Torsional pendulum consists of a heavy metal sphere or cylinder suspended from a rigid support by means of the experimental wire. Let it be given a slight rotation in the horizontal plane by applying a couple. The sphere or cylinder will execute torsional oscillations.

**Theory**: When the disk is turned through a small angle, it executes horizontal oscillations about the axis of the wire. The period of oscillations is given by

$$T = 2\pi \sqrt{\frac{I}{C}} \quad (1)$$

Where, $I$ --- Moment of inertia of the disc about the axis of rotation

$C$ --- Couple per unit twist of the wire.

$$\text{But } C = \frac{\pi \eta a^4}{2\ell} \quad (2)$$

Where, ‘$a$’ is the radius of the wire

‘$\ell$’ is the length and $\eta$ is the rigidity modulus.

From (1) and (2) we have,

$$\eta = \frac{8\pi \ell}{a^4} \frac{I}{T^2}$$

$$\eta = \frac{8\pi \ell}{a^4} \frac{\ell}{T^2} \text{ dynes/cm}^2.$$

In the case of a circular disc whose geometric axis coincides the axis of rotation, the moment of inertia $I$ is given by,

$$I = MR^2/2$$

Where $M$ is the mass of the disc and $R$ is the radius.

On substituting the value of ‘$I$’ in equation (2), we get

$$\eta = \frac{8\pi}{a^4} \frac{MR^2}{2} \frac{\ell}{T^2} \text{ dynes/cm}^2.$$

**Formulae**:

$$\eta = \frac{8\pi}{a^4} \frac{MR^2}{2} \frac{\ell}{T^2} \text{ dynes/cm}^2.$$

Where, $\eta$ → Rigidity Modulus

$M$ → Mass of the disc

$R$ → Radius of the disc

$L$ → Length of the wire

$T$ → Time period of the torsional pendulum

$a$ → Radius of the wire
Procedure:
1. Remove the kinks, if any in the wire and suspend the given disc as shown.
2. Adjust the length (l) of the wire between the chucks to be say, 50 cm.
3. When the disc is in its equilibrium position, make a chalk mark on the curved edge of the disc facing you and keep a vertical pointer in front of the disc so that when you look straight the pointer screens the chalk mark from view.
4. Set the disc to oscillate by gently turning the disc through a small angle and then release it. Such that it makes angular simple harmonic oscillations. There should not be any up and down and lateral movements of the disc. If there are any such movements, damp the oscillations and once again set the disc to oscillate. Leave off the first few oscillations and find out the time for 20 oscillations by means of a stop watch.
5. Again by a second trial find time for 20 oscillations for the same length and find the mean time for 20 oscillations.
6. Hence, calculate the period of oscillation (T).
7. Repeat the experiment for four or five lengths by increasing the length of the wire in steps of 10 cm. And tabulate readings as shown.
8. Since the radius ‘a’ of the wire occurs to the fourth power in the formula, it must be found as accurately as possible. So with screw gauge determine the diameter of the wire at 3 or 4 places equally spaced along its length and at each place measure it in two mutually perpendicular directions. Thus, find the mean value of the radius ‘a’ of the wire.
9. Find the mass ‘M’ of the disc with a rough balance. Measure the diameter of the wooden disc with help of a thread and then calculate the radius of a circular wooden disc (R)

Graph: Draw a graph with ‘ℓ’ on X-axis and ‘T^2’ on Y-axis. From the equation (A) it is evident that this graph should be linear. From the graph find out the value of T for as large ‘ℓ’ value as possible, substitute their values also in equation (A) and calculate

\[ η_{\text{Copper}} = 4.835 \times 10^{11} \text{ dynes/cm}^2. \]

Precautions: 1) The wire should be free from kinks.
2) The disc should not wobble.
3) Damped oscillations should not be considered.

Result:
Observations:
1) Mass of the disc $M = \text{gm.}$

2) Circumference of the disc $2\pi R = L \text{ cm.}$

Mean radius of the disc $R = L/2\pi \text{ cm}$

3) Table for diameter of the wire $d =$

L.C. of screw gauge = pitch of the screw / no. of head scale divisions

$= 0.1\text{mm} / 100 = 0.01 \text{ mm}$

Error:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>P.S.R. mm</th>
<th>H.S.R.</th>
<th>CHSR</th>
<th>L.C*CHSR mm</th>
<th>TR = P.S.R+(L.C X CHSR) d = mm</th>
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Average $d = \text{mm.} = \text{cm.}$

Mean radius of the wire ‘a’ = $d/2 = \text{mm.} = \text{cm.}$

4) Moment of inertia of the disc is $I = MR^2/2. \text{ gm-cm}^2$
   Where $R$ is the radius of the disc.

5) Determination of $\ell / T^2$ :

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Length of the wire between chucks ‘$\ell$’ cm.</th>
<th>Time for 20 Oscillations</th>
<th>$T = t/20$ sec</th>
<th>$T$ sec</th>
<th>$\ell / T^2$ Cm/sec$^2$</th>
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<td></td>
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<td>Trial II</td>
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Average $\ell / T^2 = \text{cm/sec}^2$

$\eta = \frac{8\pi MR^2 \ell}{a^4} \frac{\ell}{T^2} \text{ dynes/cm}^2. \text{ --------(A)}$
Torsional Pendulum

1. What is a torsional pendulum?
2. Which type of rigid bodies can we use for a torsional pendulum?
3. Why it is called a torsional pendulum?
4. How does the pendulum oscillate?
5. On what factors, does the time period of oscillation of a torsional pendulum depend?
6. What are damped oscillations?
7. What type of wire do you prefer for this experiment?
8. How will you determine the rigidity of fluids?
9. What is rigidity modulus?
10. What is couple?
11. What is the aim of this experiment?
12. Why this method is called a dynamic method?
13. How do you define time period?
14. Why does the amplitude decrease with time?
15. Is the moment of inertia a vector quantity?
16. Define moment of inertia with its units & dimensions?
17. What type of oscillations do you observe in this Torsional pendulum?
18. Why is screw guage & vernier calipers used?
19. Define Rigidity Modulus with its units?
6. VOLUME RESONATOR

Aim: To verify the relation between the volume of the air in the resonator and the frequency of the note that produces resonance in it.

Apparatus: Speaker, connecting wires, aspirator bottle, beaker, pinch-cork, measuring jar and a frequency generator.

Description: The volume resonator consists of an aspirator bottle of about 2 litre capacity with a narrow cylindrical neck at the top & an outlet (opening ) to one side near the bottom. One end of a rubber tube having a pinch-cork is connected to the outlet & the other end is attached to a short glass tube. When the bottle is filled with water, the volume of the air column inside the resonator can be increased by releasing water by opening the pinch-cork.

Principle: The volume (v) of air cavity is inversely proportional to the square of the frequency (n) of the note producing resonance in it. That is, 

\[ n = \left(\frac{v}{2\pi}\right) \left(\frac{a}{LV}\right)^{1/2} \]

\[ n^2 V = \frac{v^2 a}{4\pi^2 L} = \text{Constant}(a) \]  

(1)

Where V - volume of resonating air cavity
v - velocity of sound in air
a - area of cross section of resonator neck
L - length of the neck.

Therefore \( n^2 V = \text{constant} (a) \)

Formula: \( n^2 (V+e) = \text{constant} (a) \)  

(2)

Where n - frequency of the note producing resonance = natural frequency of the note produced by the air column of the resonator.

V - volume of the resonating air in the aspirator bottle.

e - Neck correction at the mouth of the aspirator bottle (to be applied to the volume of air).

Procedure:
1. As shown in the figure, take an aspirator bottle of 1 or 2 litre, having an opening in its side near the bottom.
2. Fit it with a one-holed rubber stopper into which a short glass tube is inserted. To the open end of the glass tube connect a rubber tube and attaches a pinch cork to it.
3. Close the pinch cork and fill the aspirator with water upon to its neck.
4. Now, Take the speaker and hold it just above the neck of the aspirator bottle without touching the bottle. This speaker is connected to the oscillator (frequency generator) through which a desired frequency is taken. So, when one of the lowest frequencies is taken, let out the water slowly into a beaker.
5. When the volume of the air cavity reaches a definite volume, a sharp loud note or resonance is produced.
6. Find the position of the resonant note of maximum intensity as exactly as you can, by letting out the water slowly with the help of pinch-cock.
7. When the position of maximum intensity is thus obtained, find out the volume of the water collected in the beaker using a measuring jar. This gives the volume of the resonating air column.
8. Repeat the experiment two or three times with the same frequency and find the Mean volume \( V \) of the air in the aspirator bottle resonating with the particular frequency \( n \).
9. Next repeat the experiment for two or three different frequencies.
10. In each case find the volume of air resonating with the frequency of the oscillator and tabulate the results in tabular form.
11. Due to some neck correction \( e \) at the mouth of the aspirator bottle the actual volume of air resonating with the oscillator will be \( V + e \) but not simply \( V \). To find the neck Correction \( e \) draw a graph.
12. Hence the factor that will be strictly be constant is not \( V.n^2 \) but \( V + e).n^2 \).

**Graph:** Draw a graph with the volume \( V \) of resonating air on the Y-axis and \( 1/n^2 \) on the x-axis. A straight line will be obtained which meets the negative axis below the origin. The intercept OA on the negative y-axis gives the neck correction ‘\( e \)’.

**Precautions:**
1. The aspirator bottle should be filled with water up to its neck.
2. The pinch cork should be tight.
3. The position of maximum sound should be noted carefully.
4. The flow of water should be a continuous stream.

**Result:**
Observations:

1. Neck correction (from graph) $e = \text{ c.c.}$

<table>
<thead>
<tr>
<th>S.No</th>
<th>Frequency of supply ‘n’ Hz.</th>
<th>Volume of the resonating cavity ‘v’</th>
<th>$n^2$</th>
<th>$1/n^2$</th>
<th>$(V+e)C.C$</th>
<th>$(V+e)n^2=\text{constant}$</th>
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<tr>
<td></td>
<td>trial1</td>
<td>trial2</td>
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</table>
VOLUME RESONATOR

1. What is a resonator?
2. What is the principle of the resonator?
3. What is meant by resonance?
4. On what factors does the frequency of a resonator depend?
5. How do you judge the resonance position?
6. What is the function of water in the aspirator bottle?
7. What types of waves are produced in the air column?
8. What are the applications of resonance?
9. What are stationary waves?
10. What are compressions and rarefractions?
11. What is a tone?
12. What are applications of resonance?
13. What is an end correction?
14. What is a resonance column?
15. What type of waves are formed by Volume Resonator?
16. Define nodes anti nodes?
17. Can you name other experiment in which stationary waves are formed?
18. Define Transverse waves, stationary waves & Progressive waves?
19. Define volume with its units?
20. Define frequency with its units?
**7. Y – By Non – Uniform Bending**
(or Double Cantilever method)

**Aim:** To determine the Young’s modulus of the material of the given beam by non-uniform bending (double cantilever) method.

**Apparatus:** A metal beam of iron or steel of uniform rectangular cross section, two knife edge supporters, pin, one weight hanger, meter scale, traveling microscope, vernier calipers, screw gauge.

**Formula:** In the non-uniform bending method (double cantilever), the Young’s modulus of the material of a beam of rectangular cross section is given by

\[ Y = g \frac{\ell^3 \cdot (M / e)}{4 bd^3} \text{ dynes/cm}^2 \text{ (or) N/m}^2 \]

Here, the arrangement is as shown in the fig-1 and

- \( g = \) acceleration due to gravity (cm/s\(^2\))
- \( \ell = \) length of the beam between the two knife edge supporters (cm) [before adding weights] = \( AB \)
- \( b = \) breadth of the beam (cm)
- \( d = \) thickness of the beam (cm)
- \( M = \) Mass suspended at the middle of the beam (gm)
- \( e = \) Depression of the midpoint due to the mass \( M \) suspended at the middle (cm)

**Description:**

The experimental arrangement will be as shown in fig-1. PQ is a metal beam of iron or steel of uniform rectangular cross section. This beam is supported on two knife edge supporters A and B in a symmetric manner. That is PA = QB. At the mid point of AB that is, at the mid point N of PQ, we suspend a weight hanger from which weights can be hung. Let the mass of the weight hanger alone is \( M_0 \). Due to this mass suspended, the mid point N gets depressed. The two half portions of the beam act as two cantilevers and hence the arrangement is called a double cantilever. A pin is fixed vertically at N (to the weight hanger itself) with wax. The horizontal cross wire in the traveling microscope is adjusted to coincide tangentially with the tip of the pin and the reading on the vertical scale is noted down. It should be kept in mind here that, the pin appears inverted through the eye piece.

**Theory of experiment:**

If \( M \) is the mass suspended at the mid point N of the beam, then weight \( W = Mg \). But here we have a double cantilever and hence the weight for each cantilever will be \( W = Mg/2 \) and length of each cantilever is \( \ell/2 \). In case of a beam of rectangular cross section with \( Mg/2 \) load for a length \( \ell/2 \) we have \( Y = g \frac{\ell^3 \cdot (M / e)}{4 bd^3} \)

Here \( e \) is the depression due to a load \( Mg \).
**Procedure:** The arrangement is setup as shown in fig-1. The beam is so adjusted to have PA = QB. Now, the weight hanger alone is suspended from N. Let the mass of weight hanger is \( M_0 \). The horizontal cross wire in the eye piece of traveling microscope is adjusted to coincide tangentially with the tip of the pin and the reading on the vertical scale is noted as \( Z_0 \). The value of \( M_0 \) need not be known to us.

Next an additional 200gm mass is added to the weight hanger and the corresponding reading \( (z) \) is noted. This process is continued in steps of adding 200gm. Up to 1000gm. [in the case of a wooden beam the masses should be 50gm and final mass 300gm only] Next, the masses are reduced gradually each time by 200gm and again the microscope readings \( (z) \) are noted. The readings are tabulated in the given observation tables. The length of the beam ‘\( ℓ \)’ between A and B is measured with a meter scale. The breadth\( (b) \) of the beam is measured at four different places with a vernier calipers. Readings are entered in table-3. The thickness ‘\( d \)’ of the beam is measured at six different places with a screw gauge. From the observations.

Average value of \( M/e \) is found.

A graph is drawn with ‘\( M \)’ on x-axis and correspondingly ‘\( e \)’ on y axis and \( (M/e) \) is found from the graph also.

Using these values of \( M/e \) we can immediately calculate \( y \).

The experiment may be repeated 2 or 3 times by changing the length \( ℓ = AB \) of the beam between A and B knife edges.

From graph \( (M/e) = \)

**Precautions:**

1. The beam should be placed symmetrically on the knife edges. That is PA = QB
2. Weight hanger should be suspended exactly at the mid point N of the beam
3. The adjustment screw on the vertical scale of the traveling microscope should be always rotated in the same direction. Otherwise there will arise ‘Black lash error’. The adjustment to get all the readings by moving the screw only in one direction should be attended to in the beginning itself.
4. The weights should be added in the weight longer in a regular fashion and in an orderly manner and in a smooth way. While adding or removing the weights, care should be taken to see that the symmetric arrangements are not disturbed.

**Result:**

Lecturer signature with date:
Observations:

Readings on the vertical scale of the traveling microscope
1 main scale division \( S = 0.05 \text{cm} \)
Total number of vernier divisions \( N = 50 \)
Least count of vernier \( l.c = S/N = 0.05 \text{cm}/50 = 0.001 \text{cm} \)

<table>
<thead>
<tr>
<th>Mass added (M) (gm)</th>
<th>Main scale reading ‘a’ cm</th>
<th>Vernier coincidence ‘n’</th>
<th>Vernier measurement ( b = n \times l.c = n \times 0.001 \text{cm} )</th>
<th>Total reading ( (a+b)\text{cm} = Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight hanger only ( M_0 )</td>
<td></td>
<td></td>
<td>( Z_0 )</td>
<td></td>
</tr>
<tr>
<td>200gm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400gm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600gm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>800gm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000gm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Above \( M-Z \) values are transferred into table – 2.

Table -2: Readings of \( M \) and \( e \) :

<table>
<thead>
<tr>
<th>Mass added ( M ) gm</th>
<th>Reading on the vertical scale of traveling Microscope (3)</th>
<th>Elevation of ( N ) for load on ( e = Z - Z_0 )</th>
<th>( M/e ) values gm/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load increasing</td>
<td>Load decreasing</td>
<td>Mean (3)</td>
<td>( Z_0 )</td>
</tr>
<tr>
<td>Weight hanger only ( M = M_0 )</td>
<td></td>
<td></td>
<td>( Z_0 )</td>
</tr>
<tr>
<td>200gm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400gm</td>
<td></td>
<td></td>
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<td>600gm</td>
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<td>800gm</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1000gm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average value of \( M/e = \) gm/cm

Table 3: Breadth(b) of the beam with a vernier calipers:
1 main scale division \( S = 0.1 \text{cm} \)
Total number of vernier divisions \( n = 10 \)
Least count of vernier \( l.c = S/n = 0.1 \text{cm}/10 = 0.01 \text{cm} \)
<table>
<thead>
<tr>
<th>S.No</th>
<th>Main scale reading (a) cm</th>
<th>Vernier coincidence ‘n’</th>
<th>b = n X l.c = n X 0.01 cm</th>
<th>Breadth B = Total reading (a + b) cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average breadth of the beam b = \( \text{cm} \)

**Table-4:** Thickness (d) of the beam with a screw guage

Pitch of the screw = 1 mm  
Number of Head scale divisions = 100  
Least count of screw gauge (l.c) = Pitch of the screw / No. of head scale divisions  
\[ = \frac{1 \text{mm}}{100} = 0.01 \text{mm} \]

Zero error correction = \( \text{Head scale divisions} \)

<table>
<thead>
<tr>
<th>S.No</th>
<th>Pitch scale reading ‘a’ mm</th>
<th>Head scale reading</th>
<th>Head scale measurement b cm = n X l.c = n X 0.01 mm</th>
<th>Total reading (a + b) mm of the beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ d = \text{mm} = \text{cm} \]

**Calculations:**

1. Average value of \((M/e)\) from table-2 = \( \text{gm/cm} \)
2. Distance between knife edges \( l = \text{cm} \)
3. Breadth of the beam \( b = \text{cm} \)
4. Thickness of the beam \( d = \text{cm} \)
5. Acceleration due to gravity \( g = \text{cm/s}^2 \)

Young’s modulus of the material of the beam \[ Y = \frac{g f^3 (M / e)}{4 b d^3} \text{ dynes/cm}^2 = \text{N/m}^2 \]

The value of \( Y \) in dynes/cm² is to be divided by 10 to get the numerical values of \( Y \) in N/m²

2. \( M/e \) from graph =

\[ Y = \frac{g f^3 (M / e \text{ from the graph})}{4 b d^3} \text{ dynes/cm}^2 = \text{N/m}^2 \]
8. A. Time dilation

**Aim:** To determine time dilation between two systems when a spaceship is flying at distance of 5 light hours at different speeds.

Formula: \[ t^1 = t \sqrt{1 - \frac{v^2}{c^2}} \]

- \( t^1 \): Time indicated by the spaceship clock
- \( t \): Time indicated by the clocks of the Earth-Pluto-system
- \( v \): Speed of the spacecraft relatively to the system of Earth and Pluto
- \( c \): Speed of light (\( c = 3 \times 10^8 \text{ m/s} \))

**Theory:** The theory which deals with the relativity of motion and rest is called theory of relativity. It is divided into two parts Special theory and General theory.

The Special theory of relativity deals with object and systems which are either moving at a constant speed with respect to one another or at rest.

The General theory of relativity deals with the object or systems which are speeding up or slowing down with respect to one another.

Time dilation is the phenomenon where two objects moving relative to each other experience different rates of time flow.

**Procedure:**

a. Click start

b. Double click physics practicals

c. Double click ph(11e)

d. Double click ph(11e)

e. Double click Time dilation.

You are ready for the experiment on "Time dilation".

1. To analyze the Time dilation between two systems read the write up fully to Start the experiment.
2. Double click on time dilation.
3. Now observe the flying time of earth system (\( t \)) and flying time of spacecraft system (\( t^1 \)) by changing the speed.
4. By applying the conditions observe the time dilation between the Spaceship and Earth-Pluto systems.
5. When \( v \) is very small compared to \( c \) then \( t^1 = t \).
6. When \( v \) is compared to \( c \) then \( t^1 < t \).

**Result:**
### Observations:

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Speed of spaceship(v)</th>
<th>Flying time of Earth-Pluto system(t)</th>
<th>Flying time of Spaceship system(t₁)</th>
<th>Time dilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>V &lt; C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>V = C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8. B. KEPLER’S LAWS

Aim: To study and analyze Kepler’s laws.

Principle and Formulae: Kepler's three laws of planetary motion can be described as follows:

- The path of the planets about the sun is elliptical in shape, with the center of the sun being located at one focus. (The Law of Ellipses)
- An imaginary line drawn from the center of the sun to the center of the planet will sweep out equal areas in equal intervals of time. (The Law of Equal Areas)
- The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun. (The Law of Harmonies)

Formulae used:

Law of Ellipses: All planets move in elliptical orbits, with the sun at one focus.

This is one of Kepler's laws. The elliptical shape of the orbit is a result of the inverse square force of gravity. The eccentricity of the ellipse is greatly exaggerated here.

An ellipse is defined as the set of points that satisfies the equation

\[ r + r' = 2a \]

In cartesian coordinates with the x-axis horizontal, the ellipse equation is
The ellipse may be seen to be a conic section, a curve obtained by slicing a circular cone. A slice perpendicular to the axis gives the special case of a circle.

For the description of an elliptic orbit, it is convenient to express the orbital position in polar coordinates, using the angle $\theta$:

$$r = \frac{a(1-e^2)}{1+e\cos\theta} \quad (0 \leq e < 1)$$

This form makes it convenient to determine the aphelion and perihelion of an elliptic orbit. The area of an ellipse is given by

$$A = \pi ab$$

Each of the conic sections can be described in terms of a semimajor axis $a$ and an eccentricity $e$. Representative values for these parameters are shown along with the types of orbits which are associated with them.
A. Law of Equal Areas: This is one of Kepler's laws. This empirical law discovered by Kepler arises from conservation of angular momentum. When the planet is closer to the sun, it moves faster, sweeping through a longer path in a given time.

*A line that connects a planet to the sun sweeps out equal areas in equal times.*

B. Law of Harmonies:

<table>
<thead>
<tr>
<th>Planet</th>
<th>Period (s)</th>
<th>Average Distance (m)</th>
<th>T^2/R^3 (s^2/m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td>3.156 x 10^7 s</td>
<td>1.4957 x 10^{11}</td>
<td>2.977 x 10^{-19}</td>
</tr>
<tr>
<td>Mars</td>
<td>5.93 x 10^7 s</td>
<td>2.278 x 10^{11}</td>
<td>2.975 x 10^{-19}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planet</th>
<th>Period (yr)</th>
<th>Average Distance (au)</th>
<th>T^2/R^3 (yr^2/au^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0.241</td>
<td>0.39</td>
<td>0.98</td>
</tr>
<tr>
<td>Venus</td>
<td>0.615</td>
<td>0.72</td>
<td>1.01</td>
</tr>
<tr>
<td>Earth</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Mars</td>
<td>1.88</td>
<td>1.52</td>
<td>1.01</td>
</tr>
<tr>
<td>Jupiter</td>
<td>11.8</td>
<td>5.20</td>
<td>0.99</td>
</tr>
<tr>
<td>Saturn</td>
<td>29.5</td>
<td>9.54</td>
<td>1.00</td>
</tr>
<tr>
<td>Uranus</td>
<td>84.0</td>
<td>19.18</td>
<td>1.00</td>
</tr>
<tr>
<td>Neptune</td>
<td>165</td>
<td>30.06</td>
<td>1.00</td>
</tr>
<tr>
<td>Pluto</td>
<td>248</td>
<td>39.44</td>
<td>1.00</td>
</tr>
</tbody>
</table>

the orbit of an imaginary celestial body by entering its semimajor axis and numerical eccentricity (less than 1). The program will calculate the length of the semiminor axis and the current, the minimal and the maximal distance from the Sun. These lengths are given in astronomical units (AU). 1 AU = 1.49597870 x 10^{11} m is defined as the average distance between Earth and Sun.
**Halley's Comet** is a short-period comet visible from Earth. Halley is the only known short-period comet that is clearly visible to the naked eye from Earth, and the only naked-eye comet that might appear twice in a human lifetime.

**Procedure:**

a. Click Start
b. Double Click Physics Practical
c. Double Click Ph(11e)
d. Double Click Ph(11e)
e. Double Click for the respective experiment Keplerlaw1 and also keplerlaw2

You are ready for the experiment on
1. Study Kepler laws.
2. Read the write up fully to start the experiment.
   For kepler’s law 1:
3. Select the corresponding planet from the list.
4. Input the values for semi major axis, semi minor axis, numerical eccentricity.
5. Observe the path between sun and the planet respectively i.e elliptical path, axes, connecting lines by selecting one after other planet.
6. Note down the distance from the sun currently, maximum and minimum values of distances also.

Analyze the values obtained and submit your project.

<table>
<thead>
<tr>
<th>s.no</th>
<th>Name of the planet</th>
<th>eccentricity</th>
<th>Semi major axis</th>
<th>Semi minor axis</th>
<th>Shape observed</th>
<th>distance of the planet from the sun</th>
</tr>
</thead>
</table>

**Result:**

Lecturer signature with date:

Department of Physics
R.B.V.R.R. Women’s College (Autonomous)