Laboratory Manual

Course code: PHY 1202
Course title: Physics Laboratory

Department of Physics
Jashore University of Science and Technology

Prepared by:
Dr. Mohammad Abdur Rashid

List of Experiments:

1.	To determine the modulus of rigidity of the material of a wire by the method of oscillation (Dynamic method).
2.	To determine the spring constant and effective mass of a given spiral spring.
3.	To determine the surface tension of a liquid by capillary tube method.
4.	To verify Stokes' law and hence to determine the viscosity of glycerin.
5.	To determine the value of acceleration due to gravity by means of a compound pendulum.
6.	To determine the moment of inertia of a flywheel about its axis of rotation.
7.	To determine the Young's modulus for the material of a wire by Searle's apparatus.
8.	To determine Young's modulus, rigidity modulus and Poisson's ratio of a short wire by Searle's dynamic method.
9.	To study the B-H loop and magnetization curve for the given magnetic loop.

Reference Books:

1. **Practical Physics** *by* Dr. Giasuddin Ahmed and Md. Shahabuddin
2. **Physics-I & II** *by* R. Resnick, D. Halliday
3. **Practical Physics** *by* RK Shukla, Anchal Srivastava

Experiment no 1: **Date:**

Name of the Experiment: Determination of the modulus of rigidity of the material of a wire by the method of oscillations (Dynamic Method).

Theory:

A cylindrical body is supported by a vertical wire of length l and radius r as shown in Fig. 1.1. The axis of the wire passes through its center of gravity. If the body is twisted through an angle and released, it will execute torsional oscillations about a vertical axis. Therefore, the motion is simple harmonic. If at any instant the angle of twist is θ, the moment of the torsional couple exerted by the wire will be

$$\frac{\eta \pi r^4}{2l}\theta = C\theta,$$

where $C = \frac{\eta\pi r^4}{2l}$ is a constant and η is the modulus of rigidity of the material of the wire.

Therefore, the time period for torsional oscillations is,

$$T = 2\pi\sqrt{\frac{I}{C}},$$

where I is the moment of inertia of the cylindrical body which is given by $I = \frac{1}{2}Ma^2$. Here M and a are the mass and radius of the cylinder respectively.

From above two equations, we get

$$T^2 = \frac{4\pi^2 I}{C} = \frac{8\pi I l}{\eta r^4}$$

$$\text{or, } \eta = \frac{8\pi I l}{T^2 r^4} \text{ dynes/cm}^2$$

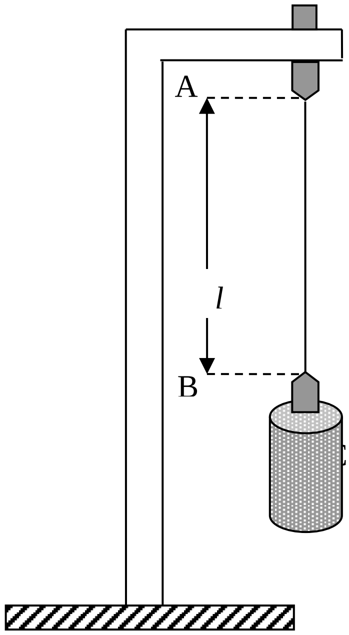


Fig. 1.1: Torsional pendulum

Apparatus:

A uniform wire, A cylindrical bar, Suitable clamp, Stopwatch, Screw gauge, Slide calipers, Meter scale, etc.

Brief Procedure:

1. Find out the value of one smallest division of the main scale and the total number of divisions of the vernier scale of the slide calipers and calculate vernier constant ($V.C$).
2. Find out the value of one smallest division of the linear scale, value of pitch (the distance along the linear scale traveled by circular scale when it completes one rotation) and the total number of divisions of the circular scale of the screw gauge and calculate least count ($L.C$).
3. Measure the radius, a of the cylinder by using the slide calipers.
4. Measure the mass, M of the cylinder. Calculate moment of inertia.
5. Measure the radius, r of the wire by using the screw gauge.
6. Measure the length, l of the wire between the point of suspension and the point at which the wire is attached to the cylinder with a meter scale.

7. Twist the cylinder from its equilibrium position through a small angle and release so that it begins to oscillate. Measure the time for 30 complete oscillations with a stop watch. Find out the time period of oscillation.
8. Calculate the value of the modulus of rigidity (η) of the material of the given wire.

Experimental Data:

Vernier Constant ($V.C.$) of the slide calipers,

$$V.\ C. = \frac{The\ value\ of\ one\ smallest\ division\ of\ the\ main\ scale}{Total\ number\ of\ divisions\ in\ the\ vernier\ scale}$$

Table-1: Table for the radius of the cylinder

No. of obs.	Main scale reading, x (cm)	Vernier scale division, d	Vernier constant, V_C (cm)	Vernier scale reading, $y = V_c \times d$ (cm)	Diameter, $x + y$ (cm)	Mean diameter, D (cm)	Instru-mental error (cm)	Corrected diameter, D (cm)	Radius, $a = \frac{D}{2}$ (cm)
1									
2									
3									
4									
5									

Least Count (L.C.) of the Screw Gauge

$$L.\,C. = \frac{Pitch}{Total\ number\ of\ divisions\ in\ the\ circular\ scale}$$

Table-2: Table for the radius of the wire

No. of obs.	Linear scale reading, x (cm)	Circular scale division, d	Least count, L_c (cm)	Circular scale reading, $y = d \times L_c$ (cm)	Diameter, $x + y$ (cm)	Mean diameter, D (cm)	Instru-mental error (cm)	Corrected diameter, D (cm)	Radius, $r = \frac{D}{2}$ (cm)
1									
2									
3									
4									
5									

Length of the wire, l = cm

Table-3: Table for the time period

No. of obs.	Time for 30 oscillations, t (sec)	Time period, $T = \frac{t}{30}$ (sec)	Mean T (sec)
1			
2			
3			
4			
5			

Calculations:

Moment of Inertia of the cylinder, $I = \frac{1}{2} Ma^2$ g-cm^2

Modulus of rigidity of the wire, $\eta = \frac{8\pi I l}{T^2 r^4}$ dynes/cm^2

Error Calculation:

Standard value of the modulus of rigidity of the material of the wire (steel) =
8.4×10^{11} dynes cm^{-2}.

$$\text{Percentage error} = \frac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$$

Result:

Discussions:

Experiment no 2: **Date:**

Name of the Experiment: Determination of the spring constant and effective mass of a given spiral spring.

Theory:

When a spiral spring clamped vertically at upper end P (Fig. 9.1) and subjected to applied load, m_o at its lower end, then the extension l becomes proportional to the applied force i.e.

$$F = k\,l$$
$$m_o\,g = k\,l$$

or,

$$k = \frac{m_o g}{l} \ldots\ldots\ldots\ldots (1),$$

where k is a constant of proportionality called spring constant.

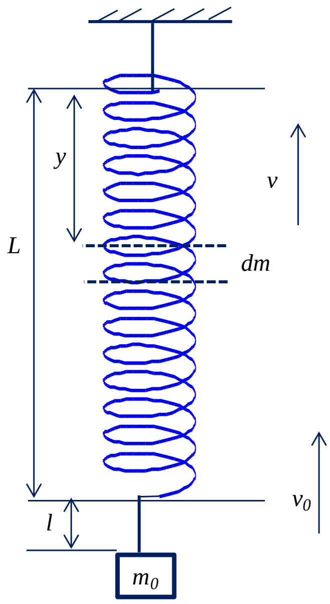


Fig.2.1: Spring-mass system

The theoretical period of a system composed of a mass M oscillating at the end of a mass less spring of force constant k is given by,

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

Since no spring is mass less, it would be more correct to use the equation

$$T = 2\pi\sqrt{\frac{m_0 + m_s}{k}},$$

where m_0 is the load and m_s is the mass of the spring.

For a spring of length L oscillating vertically (as shown in Fig. 2.1), the value of m_s can be derived from kinetic energy (E_k) consideration as

$$E_k = \int_0^L \frac{1}{2} v^2 dm,$$

where v is the velocity of the infinitesimal mass dm.

Now, assuming homogeneous stretching and uniform mass distribution, $dm = \frac{m_s}{L} dy$.

Let m_0 and dm are moving with velocities v_0 and v, respectively, where $v < v_0$.

Considering the velocity as the linear function of the position y measured from a fixed point P, v can be represented by

$$v = \frac{v_0}{L} y.$$

From the above equations,

$$E_k = \int_0^L \frac{1}{2} (\frac{v_0}{L})^2 y^2 \frac{m_s}{L} dy = \frac{1}{2} \frac{v_0^2}{L^3} m_s \int_0^L y^2 dy$$

$$E_k = \frac{1}{2} \frac{m_s}{3} v_0^2 = \frac{1}{2} m' v_0^2,$$

where $m' = \frac{1}{3} m_s$, is the effective mass of the spring.

Apparatus:

A spiral spring, Load, Electronic balance, Stopwatch and meter scale, etc.

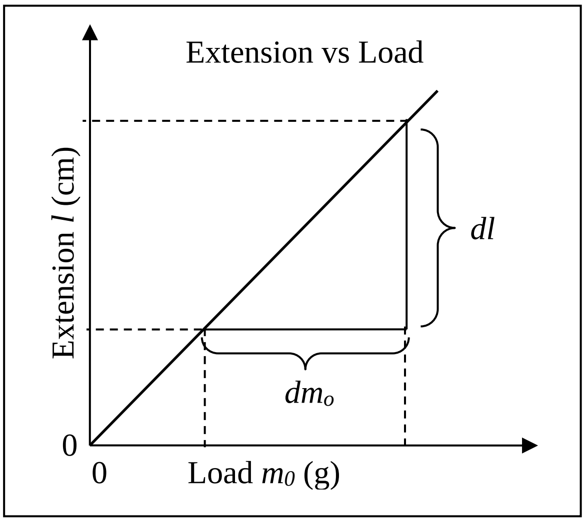
Brief Procedure:

1. Measure the mass (m_s) of the spring with a balance.
2. Clamp the spring vertically by a hook attached to a rigid frame.
3. Measure the length of the spring with a meter scale.
4. Add 100 gm load (m_0) to the free end of the spring. Measure the length of the spring with load. Calculate the extension of the spring.
5. Oscillate the spring with 100 gm load along the vertical axis and record the time for 20 complete oscillations. Then calculate the time period.
6. Repeat steps 4 and 5 for 8 to 10 sets of loads.
7. Draw a best fit straight line through origin with load as abscissa and extension as ordinate (Graph 1). Determine the slope of the line and calculate the spring constant k.
8. Plot another graph with T^2 (ordinate) against m_0 (abscissa) as shown in Graph 2. Find out the effective mass (m') by taking the point of intercept of the resulting lines on m_0 axis.

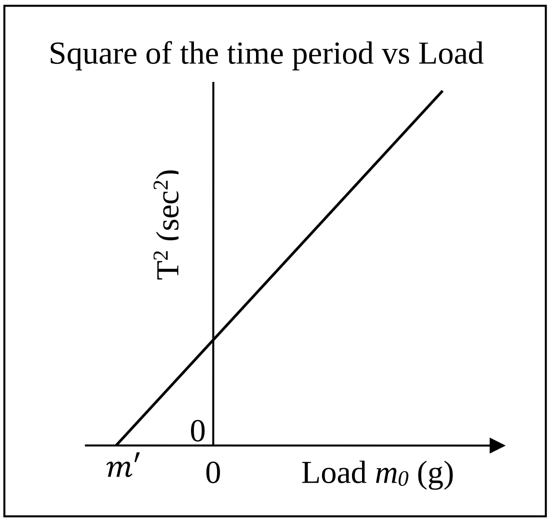
Experimental Data:

Table-1: Table for determining extensions and time periods

No. of obs.	Loads, m_0 (gm)	Length of the Spring without load, L_1 (cm)	Length of the Spring with load, L_2 (cm)	Extension, $l = L_2 - L_1$ (cm)	Time for 20 vibrations (sec)		Mean Time, t (sec)	Time Period, $T=t/20$ (sec)	T^2 (sec^2)
1	100								
2	200								
3	300								
4	400								
5	500								
6	600								
7	700								
8	800								
9	900								
10	1000								



Graph-1



Graph-2

Calculations:

From graph-1, Slope $= \frac{dl}{dm_o} = \frac{l}{m_o} =$ cm/g

Spring constant, $k = g\frac{m_o}{l} = 981 \times \frac{1}{Slope}$ *dynes/cm*

From graph-2, the effective mass of the spring, $m' =$ g

Error Calculation:

Standard value of the effective mass of the spring $= \frac{m_s}{3} =$ g

Percentage error $= \frac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$

Results:

Discussions:

Experiment no 3: **Date:**

Name of the Experiment: Determination of the Surface tension of water by capillary tube method.

Theory:

The surface tension of a liquid is the force acting perpendicular to each centimeter of the imaginary line in the plane of the surface. If one end of a clean fine capillary tube is dipped into a liquid, the liquid rises up the tube through a height *h* (Fig. 3).

The surface tension, T acts upwards along the tangent to the meniscus. The component of T acting vertically upwards is $T\cos\theta$ and the total force acting upwards is $T\cos\theta\times 2\pi r$, where r is the internal radius of the capillary tube. This is the upward force due to surface tension of the liquid.

The weight of the liquid column acting downwards is equal to $V\times\rho\times g$, where ρ is the density of the liquid and g is the acceleration due to gravity.

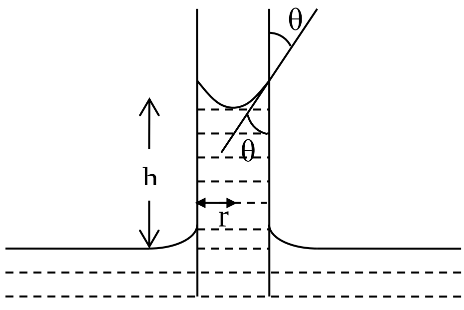


Fig. 3: Rise of water through the capillary tube.

The volume $V = \pi r^2 h$ + volume of the meniscus for a tube of uniform bore.

If the radius r is small, the meniscus = (volume of a cylinder of radius r and height h) – (volume of hemisphere of radius r). This can be written as

$$\text{Volume of meniscus} = \pi r^3 - \frac{2}{3}\pi r^3 = \frac{1}{3}\pi r^3$$

$$\text{Therefore, } V = \pi r^2 h + \frac{1}{3}\pi r^3 = \pi r^2\left(h + \frac{1}{3}r\right)$$

$$\text{Hence, weight of the liquid column} = \pi r^2\left(h + \frac{1}{3}r\right)\rho g$$

Since the column is in equilibrium, the upward force due to surface tension must support the weight of the liquid column. Hence, for equilibrium,

$$T\cos\theta\times 2\pi r = \pi r^2\left(h + \frac{1}{3}r\right)\rho g$$

For water, $\theta = 0$ and hence $\cos\theta = 1$. So the above relation gives,

$$T = \frac{1}{2}\rho g r\left(h + \frac{1}{3}r\right) \text{ dynes/cm.}$$

Apparatus:

Capillary tube with fine bore, Traveling microscope, Needle, Beaker, Clamp, Stand, etc.

Brief Procedure:

1. Find out the Vernier constant (*V. C.*) of the two scales of the travelling microscope using the formula as provided in experiment no. 1.
2. Take some water in a clean beaker. Hold a glass plate *G* in a clamp and attach the capillary tube *A* to it with wax. Place the glass plate in such a position that the capillary tube is vertical and its end dip well in the water. Water will rise in the tube.
3. Place the needle *N*, horizontally on the base of the travelling microscope and take the readings at its two ends from the horizontal scale. The difference of these two readings will give the length *l*, of the needle.
4. Place the needle by the side of the capillary tube and adjust its position in such a way that its lower tip is just above the water surface of the beaker.
5. Focus the microscope on the needle and adjust it such that the horizontal cross-wire coincides with the top of the needle. Read the vertical scale of the microscope and record the data.
6. Adjust the height of the microscope such that its horizontal cross-wire just touches the lower meniscus in the tube *A*. It will appear as an inverted image in the eye piece of the microscope. Read the scale of the microscope. Take the difference of this reading and the reading in step 5. If the top of the needle stands above the water meniscus in the tube, subtract this difference from the length of the needle to get the height of the water column in the tube, h. If the top of the needle stands below the meniscus add this difference to the length of the needle to get h.
7. Now break the capillary tube very carefully at the level of the meniscus with a file and hold it horizontally. By moving the microscope horizontally, make the vertical cross-wire tangential to the inner left side of the bore. Record the data from the horizontal scale of the microscope. Move the microscope horizontally until the vertical cross-wire is tangential to the inner right side of the bore and record the data at this position. Difference of these two readings gives the diameter of the bore. Similarly, by the vertical movement of the microscope, determine the diameter of the bore in the perpendicular position. Take the mean of these diameters found from the horizontal and vertical scale and then calculate the radius of the capillary tube.

Experimental Data:

Table-1: Data for measuring the length of the needle

Reading at	No. of obs.	Main Scale Reading, x (cm)	Vernier Scale Division, d	Vernier Constant, V_c (cm)	Vernier Scale Reading, $y = V_c \times d$ (cm)	Total $x + y$ (cm)	Mean (cm)	Length, $l = b - a$ (cm)
Left End, a	1							
	2							
	3							
	4							
	5							
Right End, b	1							
	2							
	3							
	4							
	5							

Table-2: Data for the reading of the needle head

No. of obs.	Main Scale Reading, x (cm)	Vernier Scale Division, d	Vernier Constant, V_c (cm)	Vernier Scale Reading, $y = V_c \times d$ (cm)	Total, $R_1 = x + y$ (cm)	Mean, R_1 (cm)
1						
2						
3						
4						
5						

Table-3: Data for the readings of water meniscus in the tube and height of water meniscus

No. of obs.	Main Scale Reading, x (cm)	Vernier Scale Division, d	Vernier Constant, V_c (cm)	Vernier Scale Reading, $y = V_c \times d$ (cm)	Height, $R_2 = x + y$ (cm.)	Mean height, R_2 (cm.)	$X=R_1 \sim R_2$ (cm)	Height of water meniscus $h=l \pm X$ (cm)
1								
2								
3								
4								
5								

Table-4: Data for the radius of the tubes

Direction	Left or lower end					Right or upper end					Diameter, $D = y_2 \sim y_1$ (cm)	Mean diameter D (cm)	Radius, $r = D/2$ (cm)
	Main Scale Reading, x (cm)	Vernier Scale Division, d	Vernier Constant, V_c (cm)	Vernier Scale Reading, $y = d \times V_c$ (cm)	Total, $y_2 = x + y$ (cm)	Main Scale Reading, x (cm)	Vernier Scale Division, d	Vernier Constant, V_c (cm)	Vernier Scale Reading, $y = d \times V_c$ (cm)	Total , $y_1 = x + y$ (cm)			
Horizontal (a)													
Vertical (b)													

Calculation:

Room temperature, θ˚C =

Density of water at θ˚C =

Surface Tension, $T = \frac{1}{2}\rho gr(h + \frac{1}{3}r)$

Percentage of error:

Standard value of the Surface tension of water at 25℃ is 72 dynes cm^{-1}.

Error in the experiment = $\frac{\text{Standard value} \sim \text{Experimental value}}{\text{Standard value}} \times 100\%$

Result:

Discussions:

Experiment no 4: **Date:**

Name of the Experiment: Verification of Stokes' law and hence determination of the viscosity of a liquid (Glycerin).

Theory:

When a small metal ball is left gently on the surface of a long vertical column of a viscous liquid, the ball moves vertically downwards. As the ball falls, it is accelerated initially due to gravity. However, its motion is opposed by the viscous drag of the liquid and the upward thrust due to buoyancy of the liquid until the resultant forces acting on the ball is zero. Then the body is in equilibrium and moves with a constant velocity called the terminal velocity v_t.

Stokes' showed that the opposing force F, acting on the ball, due to viscosity of the liquid is given by

$$F = 6\pi v_t r\eta,$$

where r is the radius of the ball, η is the co-efficient of viscosity of the liquid and v_t is the terminal velocity of the ball. This expression is referred to as Stokes' law.

If the density of the material of the ball is ρ, then its weight is given by
Mass × acceleration due to gravity = volume $\times \rho \times g$

$$= \frac{4}{3}\pi r^3 \rho g$$

The upward thrust due to buoyancy of the liquid is the weight of the liquid displaced by the ball.

If σ is the density of the liquid, then this up thrust on the ball is

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

Then the sum of the forces acting on the ball (considering upward forces to be positive), is

$$6\pi v_t r\eta + \frac{4}{3}\pi r^3 \rho g - \frac{4}{3}\pi r^3 \sigma = 0$$

or,

$$\eta = \frac{2}{9}\frac{r^2}{v_t} \times g(\rho - \sigma)$$

Stokes' law holds well only if the liquid is infinite both in extent and depth. Further the velocity of the ball should be less than a certain value, called the critical velocity.

Apparatus:

A measuring cylinder, Meter scale, Glycerin, Screw gauge, Stop watch, Powerful bar magnet, Small steel ball bearings of different sizes, etc.

Brief Procedure:

1. Calculate the least count (*L.C.*) of the screw gauge as explained in experiment no. 1.
2. Complete Table-1 for the radius of the ball.
3. Take one of the balls and drop it to the measuring cylinder and wait until the ball reaches well below the surface of the glycerin (say 500 ml mark). When the ball reaches to the desired mark, start the stop watch. Stop the stop watch after the ball reaches 2^{nd} mark (say 100 ml mark). Record the time in Table-2 and the distance between the two marks in centimeter.
4. Repeat step 3 for other balls.
5. Calculate the value of the viscosity for all the balls and take the mean.
6. Plot a graph of v_t against r^2. Draw a best fit line through origin and determine the slope of the line. Using the given formula, calculate the viscosity of the glycerin.

Experimental Data:

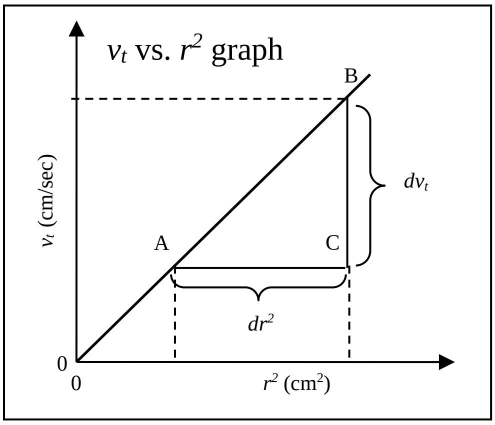
Table-1: Data for the radius of the balls:

Ball No.	No. of obs.	Linear scale reading, x (cm)	Circular scale division, d	Least count, L_c (cm)	Circular scale reading, $y = d \times L_c$ (cm)	Diameter, $D_i = x + y$ (cm)	Mean diameter, D_i (cm)	Radius, $r_i = D_i/2$ (cm)
01	1							
	2							
	3							
02	1							
	2							
	3							
03	1							
	2							
	3							
04	1							
	2							
	3							

Table-2: Data for terminal velocity (v_t) and r^2

Ball	Square of the radius of the ball, r^2(cm^2)	Distance, d (cm)	Time taken, t (sec)	Terminal velocity, $v_t=d/t$ (cm/sec)	Viscosity, η (dynes-sec/cm^2)	Mean η (dynes-sec/cm^2)
01						
02						
03						
04						

Density of steel, $\rho = 7.8$ g/cm^3 and density of glycerin, $\sigma = 1.26$ g/cm^3



Graph 1

$$\text{slope} = \frac{dv_t}{dr^2} = \frac{\text{BC}}{\text{AC}}$$

Calculation:

$$\eta = \frac{2}{9}\frac{r^2}{v_t} \times g(\rho - \sigma) = [\frac{2g}{9}(\rho - \sigma) \times \frac{1}{\text{slope}}] \text{ dynes-sec/cm}^2$$

Result:

Discussions:

Experiment no 5: **Date:**

Name of the Experiment: Determination of the value of the acceleration due to gravity (g) by means of a compound pendulum.

Theory:

A compound pendulum is a rigid body of arbitrary shape which is capable of oscillating about a horizontal axis passing through it. For small angles of swinging, its motion is simple harmonic with a period given by

$$T = 2\pi\sqrt{\frac{I}{mgh}}$$

where I is the pendulum's rotational inertia about the pivot, m is the pendulum's mass, and h is the distance between the pivot and the pendulum's centre of gravity as shown in Fig. 5.1.

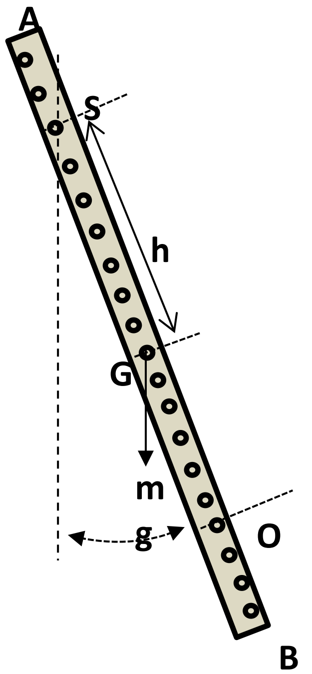


Fig. 5.1: Compound Pendulum

A compound pendulum that oscillates from a suspension point (S) with period T (as shown in Fig. 5.1) can be compared with a simple pendulum of length L with the same period T. L is called the equivalent length of the compound pendulum. The point along the compound pendulum at a distance L from the suspension point is called the oscillation point (Fig. 5.1). In a compound pendulum these two points are interchangeable.

Now using the time period expression of a simple pendulum,

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

$$\text{or, } g = 4\pi^2\frac{L}{T^2}$$

The acceleration due to gravity (g) at the place of the experiment can be measured by finding L and T graphically.

Apparatus:

A bar pendulum, Stop watch, Meter Scale, Metal wedge, etc

Brief Procedure:

1. Label the ends of the compound pendulum bar as *A* and *B*.
2. Locate the centre of gravity (*G*) of the bar.
3. Measure the distance of holes (1, 2, 3,… and 9) from *G* for both sides.
4. Insert a metal wedge in the 1st hole at end *A* and place the wedge on the clamp so that the bar can oscillate freely.
5. Oscillate the bar horizontally. Be careful not to make the amplitude of oscillation too large. (Should be less than 5°). Note the time for 20 complete oscillations. Calculate the time period.
6. Do this process at different holes (2, 3, …..and 9).
7. Repeat steps 3, 4 and 5 for end *B*.
8. Draw a graph with distance as abscissa and time period as ordinate with the origin at the centre of gravity which is put at the middle of the graph paper along the abscissa. Put the length measured towards the end A to the left and that measured toward the end B to the right of the origin (see Graph 1). Draw a line parallel to the abscissa in such a way that it intersects at four points of the two curves as shown in Graph 1. Label these points as *P, Q, R* and *S*, respectively.
9. Find out the equivalent length of the pendulum, *L* and time period, *T* (value of the period at point *O*) from the graph.
10. Calculate the value of acceleration due to gravity using the given equation.

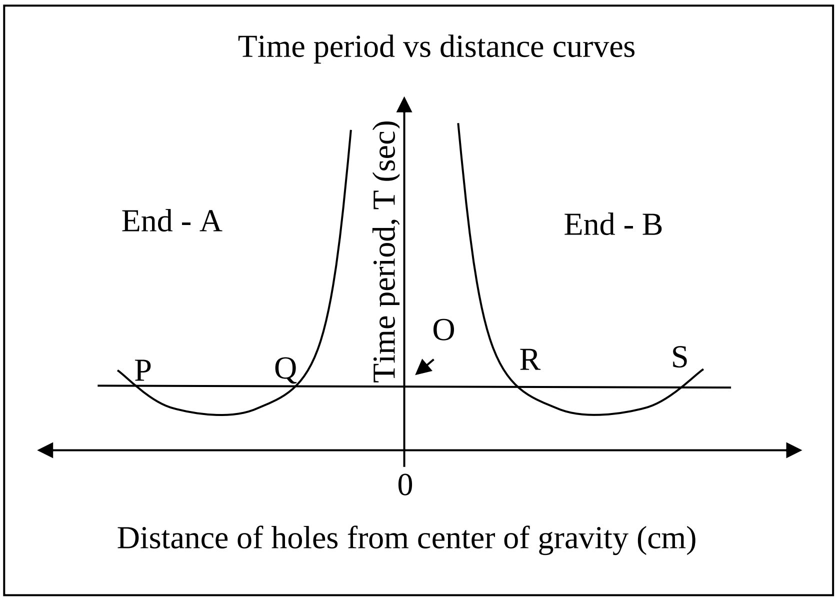
Experimental Data:

Table-1: Table for the time period for end-*A*

	Hole no.	Distance of the hole from center of gravity (cm.)	Time for 20 oscillations, (sec.)		Mean time, t (sec.)	Time period $T = \frac{t}{20}$ (sec.)
End-A	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					

Table-2: Table for the time period for end-*B*

	Hole no.	Distance of the hole from center of gravity (cm.)	Time for 20 oscillations, (sec.)		Mean time, t (sec.)	Time period $T = \frac{t}{20}$ (sec.)
End-B	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					



Graph I

Calculations:

From graph 1: Length, PR = $(PO+OR)$ = cm

Length, QS = $(QO+OS)$ = cm

Equivalent length to the Simple Pendulum, $L = \dfrac{PR+QS}{2}$ = cm

Time period, T = sec

The value of acceleration due to gravity, $g = 4\pi^2 \dfrac{L}{T^2}$ = cm/s^2

Error Calculation:

Standard value of the acceleration due to gravity = 981 cm/s^2

Percentage error = $\dfrac{Standard\ value \sim Experimental\ value}{Standard\ value} \times 100\ \%$

Result:

Discussions:

Experiment no 6: **Date:**

Name of the experiment: To determine the moment of inertia of a flywheel about its axis of rotation.

Experiment no 7: **Date:**

Name of the experiment: To determine the Young's modulus for the material of a wire by Searle's apparatus.

<u>Experiment no 8:</u> **<u>Date:</u>**

Name of the experiment: To determine Young's modulus, rigidity modulus and Poisson's ratio of a short wire by Searle's dynamic method.

<u>Experiment no 9:</u> **<u>Date:</u>**

Name of the experiment: To study the B-H loop and magnetization curve for the given magnetic loop.