EXPERIMENT 6

AIM

Using a Simple Pendulum plot L – T and L – T^2 graphs, hence find the effective length of second's pendulum using appropriate graph.

APPARATUS AND MATERIAL REQUIRED

Clamp stand; a split cork; a heavy metallic (brass/iron) spherical bob with a hook; a long, fine, strong cotton thread/string (about 2.0 m); stop-watch; metre scale, graph paper, pencil, eraser.

DESCRIPTION OF TIME MEASURING DEVICES IN A SCHOOL LABORATORY

The most common device used for measuring time in a school laboratory is a stop-watch or a stop-clock (analog). As the names suggest, these have the provision to start or stop their working as desired by the experimenter.

(a) Stop-Watch

Analog

A stop-watch is a special kind of watch. It has a multipurpose knob or button (B) for start/stop/back to zero position [Fig. E 6.1(b)]. It has two circular dials, the bigger one for a longer second's hand and the other smaller one for a shorter minute's hand. The second's dial has 30 equal divisions, each division representing 0.1 second. Before using a stop-watch you should find its least count. In one rotation, the seconds hand covers 30 seconds (marked by black colour) then in the second rotation another 30 seconds are covered (marked by red colour), therefore, the least count is 0.1 second.

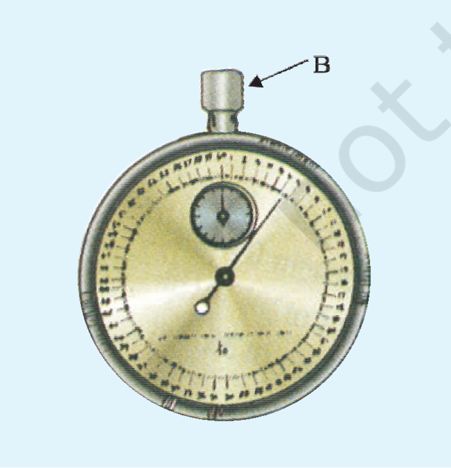

Fig.E 6.1(a): *Stop - Watch*

(b) Stop-Clock

The least count of a stop-watch is generally about 0.1s [Fig. E 6.1(b)] while that of a stop-clock is 1s, so for more accurate measurement of time intervals in a school laboratory, a stop-watch is preferred. Digital stop-watches are also available now. These watches may be started by pressing the button and can be stopped by pressing the same button once again. The lapsed time interval is directly displayed by the watch.

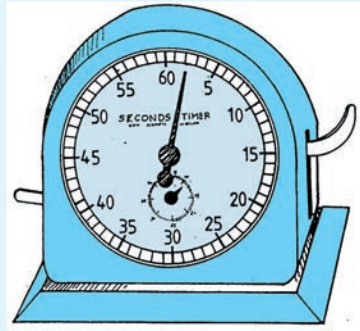

Fig.E 6.1(b): *Stop - Clock*

TERMS AND DEFINITIONS

1. **Second's pendulum:** It is a pendulum which takes precisely one second to move from one extreme position to other. Thus, its times period is precisely 2 seconds.
2. **Simple pendulum:** A point mass suspended by an inextensible, mass less string from a rigid point support. In practice a small heavy spherical bob of high density material of radius *r*, much smaller than the length of the suspension, is suspended by a light, flexible and strong string/thread supported at the other end firmly with a clamp stand. Fig. E 6.2 is a good approximation to an ideal simple pendulum.
3. **Effective length of the pendulum:** The distance L between the point of suspension and the centre of spherical bob (centre of gravity), $L = l + r + e$, is also called the effective length where l is the length of the string from the top of the bob to the hook, e, the length of the hook and r the radius of the bob.

PRINCIPLE

The simple pendulum executes **Simple Harmonic Motion** (SHM) as the acceleration of the pendulum bob is directly proportional to its displacement from the mean position and is always directed towards it.

The time period (T) of a simple pendulum for oscillations of small amplitude, is given by the relation

$$T = 2\pi\sqrt{L/g} \quad \text{(E 6.1)}$$

where L is the length of the pendulum, and g is the acceleration due to gravity at the place of experiment.

Eq. (6.1) may be rewritten as

$$T^2 = \frac{4\pi^2 L}{g} \quad \text{(E 6.2)}$$

PROCEDURE

1. Place the clamp stand on the table. Tie the hook, attached to the pendulum bob, to one end of the string of about 150 cm in length. Pass the other end of the string through two half-pieces of a split cork.

2. Clamp the split cork firmly in the clamp stand such that the line of separation of the two pieces of the split cork is at right angles to the line OA along which the pendulum oscillates [Fig. E 6.2(a)]. Mark, with a piece of chalk or ink, on the edge of the table a vertical line parallel to and just behind the vertical thread OA, the position of the bob at rest. Take care that the bob hangs vertically (about 2 cm above the floor) beyond the edge of the table so that it is free to oscillate.

3. Measure the effective length of simple pendulum as shown in Fig. E 6.2(b).

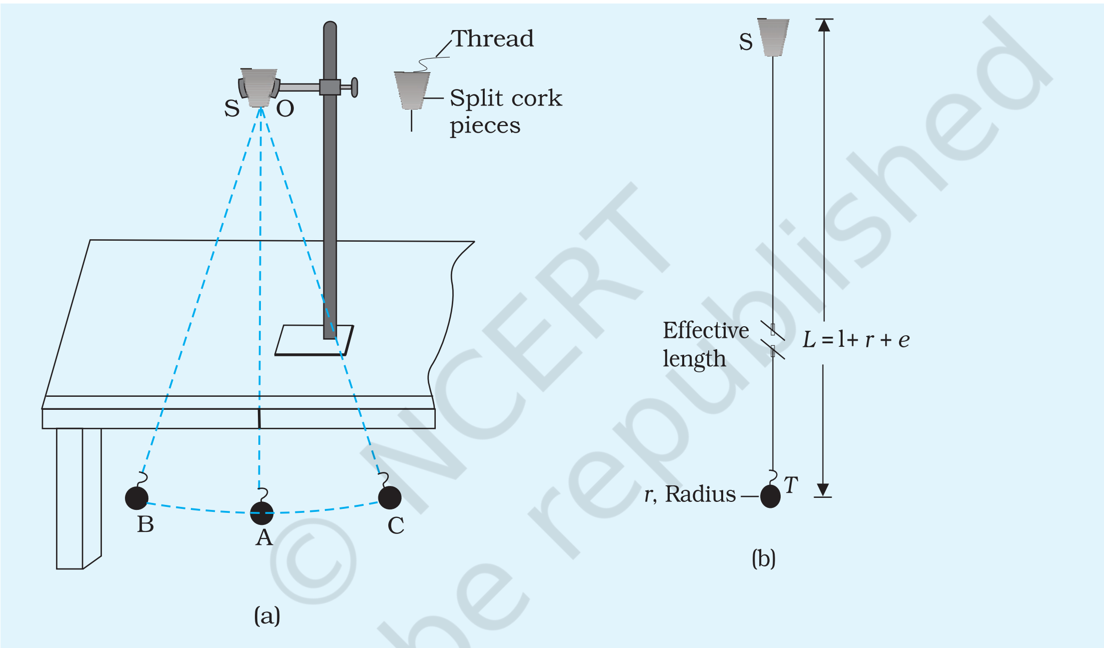

Fig.E 6.2 (a): *A simple pendulum; B and C show the extreme positions*

Fig.E 6.2 (b): *Effective length of a simple pendulum*

4. Displace the bob to one side, not more than 15 degrees angular displacement, from the vertical position OA and then release it gently. In case you find that the stand is shaky, put some heavy object on its base. Make sure that the bob starts oscillating in a vertical plane about its rest (or mean) position OA and **does not** (i) spin about its own axis, or (ii) move up and down while oscillating, or (iii) revolve in an elliptic path around its mean position.

5. Keep the pendulum oscillating for some time. After completion of a few oscillations, start the stop-watch/clock as the thread attached to the pendulum bob just crosses its mean position (say, from left to right). Count it as zero oscillation.

6. Keep on counting oscillations 1,2,3,..., *n*, everytime the bob crosses the mean position OA in the same direction (from left to right).

Stop the stop-watch/clock, at the count n (say, 20 or 25) of oscillations, i.e., just when n oscillations are complete. For better results, n should be chosen such that the time taken for n oscillations is 50 s or more. Read, the total time (t) taken by the bob for n oscillations. Repeat this observation a few times by noting the time for same number (n) of oscillations. Take the mean of these readings. Compute the time for one oscillation, i.e., the time period T (= t/n) of the pendulum.

7. Change the length of the pendulum, by about 10 cm. Repeat the step 6 again for finding the time (t) for about 20 oscillations or more for the new length and find the mean time period. Take 5 or 6 more observations for different lengths of penduLum and find mean time period in each case.

8. Record observations in the tabular form with proper units and significant figures.

9. Take effective length L along x-axis and T^2 (or T) along y-axis, using the observed values from Table E 6.1. Choose suitable scales on these axes to represent L and T^2 (or T). Plot a graph between L and T^2 (as shown in Fig. E 6.4) and also between L and T (as shown in Fig. E 6.3). What are the shapes of $L–T^2$ graph and $L–T$ graph? Identify these shapes.

OBSERVATIONS

(i) Radius (r) of the pendulum bob (given) = ... cm

Length of the hook (given) (e) = ... cm

Least count of the metre scale = ... mm = ... cm

Least count of the stop-watch/clock = ... s

Table E 6.1: Measuring the time period T and effective length L of the simple pendulum

S. No.	Length of the string from the top of the bob to the point of suspension l	Effective length, L = (l+r+e)		Number of oscillations counted, n	Time for n oscillations t (s)				Time period T (= t/n)
		(cm)	m		(i)...	(ii)	(iii)	Mean t (s)	s

PLOTTING GRAPH

(i) *L* vs *T* graphs

Plot a graph between L versus T from observations recorded in Table E 6.1, taking L along x-axis and T along y-axis. You will find that this graph is a curve, which is part of a parabola as shown in Fig. E 6.3.

(ii) *L* vs T^2 graph

Plot a graph between L versus T^2 from observations recorded in Table E 6.1, taking L along x-axis and T^2 along y-axis. You will find that the graph is a straight line passing through origin as shown in Fig. E. 6.4.

(iii) From the T^2 versus L graph locate the effective length of second's pendulum for $T^2 = 4s^2$.

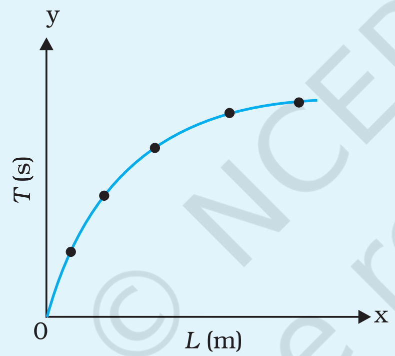

Fig. E 6.3: *Graph of L vs T*

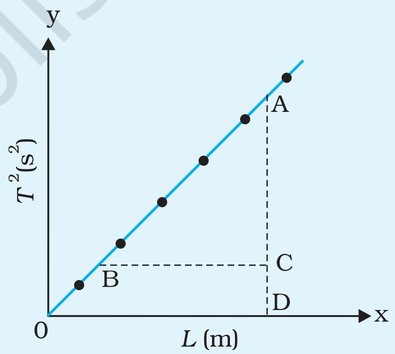

Fig. E 6.4: *Graph L vs T^2*

RESULT

1. The graph L versus T is curved, convex upwards.
2. The graph L versus T^2 is a straight line.
3. The effective length of second's pendulum from L versus T^2 graph is ... cm.

Note : The radius of bob may be found from its measured diameter with the help of callipers by placing the pendulum bob between the two jaws of (a) ordinary callipers, or (b) Vernier Callipers, as described in Experiment E 1.1 (a). It can also be found by placing the spherical bob between two parallel card boards and measuring the spacing (diameter) or distance between them with a metre scale.

DISCUSSION

1. The accuracy of the result for the length of second's pendulum depends mainly on the accuracy in measurement of effective length (using metre scale) and the time period *T* of the pendulum (using stop-watch). As the time period appears as T^2 in Eq. E 6.2, a small uncertainty in the measurement of *T* would result in appreciable error in T^2, thereby significantly affecting the result. A stop-watch with accuracy of 0.1s may be preferred over a less accurate stop-watch/clock.

2. Some personal error is always likely to be involved due to stop-watch not being started or stopped exactly at the instant the bob crosses the mean position. Take special care that you start and stop the stop-watch at the instant when pendulum bob just crosses the mean position in the same direction.

3. Sometimes air currents may not be completely eliminated. This may result in conical motion of the bob, instead of its motion in vertical plane. The spin or conical motion of the bob may cause a twist in the thread, thereby affecting the time period. Take special care that the bob, when it is taken to one side of the rest position, is released very gently.

4. To suspend the bob from the rigid support, use a thin, light, strong, unspun cotton thread instead of nylon string. Elasticity of the string is likely to cause some error in the effective length of the pendulum.

5. The simple pendulum swings to and fro in SHM about the mean, equilibrium position. Eq. (E 6.1) that expresses the relation between *T* and *L* as $T = 2\pi\sqrt{L/g}$, holds strictly true for small amplitude or swing θ of the pendulum.

   Remember that this relation is based on the assumption that sin $\theta \approx \theta$, (expressed in radian) holds only for small angular displacement θ.

6. Buoyancy of air and viscous drag due to air slightly increase the time period of the pendulum. The effect can be greatly reduced to a large extent by taking a small, heavy bob of high density material (such as iron/ steel/brass).

SELF ASSESSMENT

1. Interpret the graphs between *L* and T^2, and also between *L* and *T* that you have drawn for a simple pendulum.

2. Examine, using Table E 6.1, how the time period *T* changes as the

effective length L of a simple pendulum; becomes 2-fold, 4-fold, and so on.

3. How can you determine the value of 'g', acceleration due to gravity, from the T^2 vs L graph?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. To determine 'g', the acceleration due to gravity, at a given place, from the $L - T^2$ graph, for a simple pendulum.

2. Studying the effect of size of the bob on the time period of the simple pendulum.

   [**Hint:** With the same experimental set-up, take a few spherical bobs of same material (density) but of different sizes (diameters). Keep the length of the pendulum the same for each case. Clamp the bobs one by one, and starting from a small angular displacement of about 10°, each time measure the time for 50 oscillations. Find out the time period of the pendulum using bobs of different sizes. Compensate for difference in diameter of the bob by adjusting the length of the thread.

   Does the time period depend on the size of the pendulum bob? If yes, see the order in which the change occurs.]

3. Studying the effect of material (density) of the bob on the time period of the simple pendulum.

   [**Hint:** With the same experimental set-up, take a few spherical bobs (balls) of different materials, but of same size. Keep the length of the pendulum the same for each case. Find out, in each case starting from a small angular displacement of about 10°, the time period of the pendulum using bobs of different materials,

   Does the time period depend on the material (density) of the pendulum bob? If yes, see the order in which the change occurs. If not, then do you see an additional reason to use the pendulum for time measurement.]

4. Studying the effect of mass of the bob on the time period of the simple pendulum.

   [**Hint:** With the same experimental set-up, take a few bobs of different materials (different masses) but of same size. Keep the length of the pendulum same for each case. Starting from a small angular displacement of about 10° find out, in each case, the time period of the pendulum, using bobs of different masses.

   Does the time period depend on the mass of the pendulum bob? If yes, then see the order in which the change occurs. If not, then do you see an additional reason to use the pendulum as a time measuring device.]

5. Studying the effect of amplitude of oscillation on the time period of the simple pendulum.

   [**Hint:** With the same experimental set-up, keep the mass of the bob and length of the pendulum fixed. For measuring the angular amplitude, make a large protractor on the cardboard and have a scale marked on an arc from 0° to 90° in units of 5°. Fix it on the edge of a table by two drawing pins such that its 0°- line coincides with the suspension thread of the pendulum at rest. Start the pendulum oscillating with a very large angular amplitude (say 70°) and find the time period T of the pendulum. Change the amplitude of oscillation of the bob in small steps of 5° or 10° and determine the time period in each case till the amplitude becomes small (say 5°). Draw a graph between angular amplitude and T. How does the time period of the pendulum change with the amplitude of oscillation?

How much does the value of T for A = 10° differ from that for A= 50° from the graph you have drawn?

Find at what amplitude of oscillation , the time period begins to vary?

Determine the limit for the pendulum when it ceases to be a simple pendulum.]

6. Studying the effect on time period of a pendulum having a bob of varying mass (e.g. by filling the hollow bob with sand, sand being drained out in steps)

[**Hint:** The change in T, if any, in this experiment will be so small that it will not be possible to measure it due to the following reasons:

The centre of gravity (CG) of a hollow sphere is at the centre of the sphere. The length of this simple pendulum will be same as that of a solid sphere (same size) or that of the hollow sphere filled completely with sand (solid sphere).

Drain out some sand from the sphere. The situation is as shown in Fig. E. 6.5. The CG of bob now goes down to point say A. The effective length of the pendulum increases and therefore the T_A increases ($T_A > T_O$), some more sand is drained out, the CG goes down further to a point B. The effective length further increases, increasing T.

The process continues and L and T change in the same direction (increasing), until finally the entire sand is drained out. The bob is now a hollow sphere with CG shifting back to centre C. The time period will now become T_0 again.]

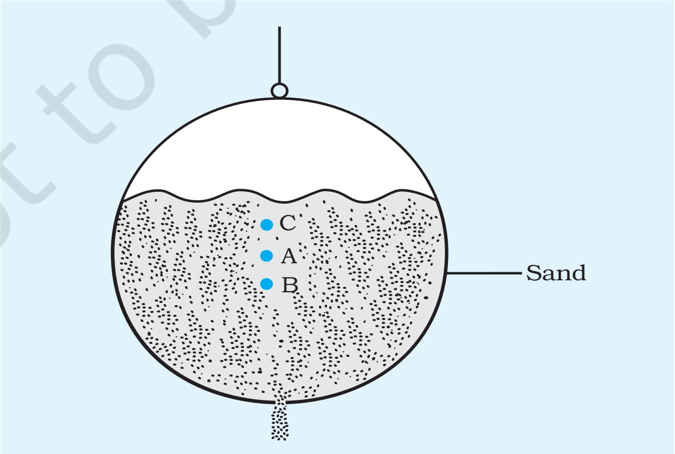

Fig. E 6.5: *Variation of centre of gravity of sand filled hollow bob on time period of the pendulum; sand being drained out of the bob in steps.*