1. Details of Module and its structure

Subject Name	Physics
Course Name	Physics 02 (Physics Part 2 ,Class XI)
Module Name/Title	Unit 10, Module 7, Simple Pendulum and Its Applications Chapter 14, Oscillations
Module Id	keph_201407_eContent
Pre-requisites	Periodic motion, periodic sine and cosine function, simple harmonic motion,phase, energy of a simple harmonic motion, periodic time, frequency
Objectives	After going through this module, the learners will be able to: • Use a simple pendulum plot its L-T^2graph and use it to find the effective length of a second's pendulum • Study variation of time period of a simple pendulum of a given length by taking bobs of same size but different masses and interpret the result • Use a simple pendulum plot its L-T^2graph and use it to calculate the acceleration due to gravity at a particular place
Keywords	Simple Pendulum, time period, effective length, Amplitude, acceleration due to gravity, dissipation of energy, experiments with simple pendulum

2. Development team

Role	Name	Affiliation
National MOOC Coordinator (NMC)	Prof. Amarendra P. Behera	Central Institute of Educational Technology, NCERT, New Delhi
Programme Coordinator	Dr. Mohd Mamur Ali	Central Institute of Educational Technology, NCERT, New Delhi
Course Coordinator / PI	Anuradha Mathur	Central Institute of Educational Technology, NCERT, New Delhi
Subject Matter Expert (SME)	Ramesh Prasad Badoni	GIC Misras Patti Dehradun Uttarakhand
Review Team	Associate Prof. N.K. Sehgal (Retd.) Prof. V. B. Bhatia (Retd.) Prof. B. K. Sharma (Retd.)	Delhi University Delhi University DESM, NCERT, New Delhi

TABLE OF CONTENTS

1. UNIT SYLLABUS

Unit 10:Oscillations and Waves

Chapter 14 oscillations

Periodic motion, time period, frequency, displacement as a function of time , periodic functions Simple harmonic motion (S.H.M) and its equation; phase; oscillations of a loaded spring-restoring force and force constant; energy in S.H.M. Kinetic and potential energies; simple pendulum derivation of expression for its time period.

Free forced and damped oscillations (qualitative ideas only) resonance

Chapter 15 Waves

Wave motion transverse and longitudinal waves, speed of wave motion , displacement, relation for a progressive wave, principle of superposition of waves , reflection of waves , standing waves in strings and organ pipes, fundamental mode and harmonics, beats,Doppler effect

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 15 MODULES

Module 1	• **Periodic motion** • **Special vocabulary** • **Time period, frequency,** • **Periodically repeating its path** • **Periodically moving back and forth about a point** • **Mechanical and non-mechanical periodic physical quantities**
Module 2	• **Simple harmonic motion** • **Ideal simple harmonic oscillator** • **Amplitude** • **Comparing periodic motions phase,**

	• Phase difference Out of phase In phase not in phase
Module 3	• Kinematics of an oscillator • Equation of motion • Using a periodic function (sine and cosine functions) • Relating periodic motion of a body revolving in a circular path of fixed radius and an Oscillator in SHM
Module 4	• Using graphs to understand kinematics of SHM • Kinetic energy and potential energy graphs of an oscillator • Understanding the relevance of mean position • Equation of the graph • Reasons why it is parabolic
Module 5	• Oscillations of a loaded spring • Reasons for oscillation • Dynamics of an oscillator • Restoring force • Spring constant • Periodic time spring factor and inertia factor
Module 6	• Simple pendulum • Oscillating pendulum • Expression for time period of a pendulum • Time period and effective length of the pendulum • Calculation of acceleration due to gravity • Factors effecting the periodic time of a pendulum • Pendulums as ‘time keepers’ and challenges • To study dissipation of energy of a simple pendulum by plotting a graph between square of amplitude and time
Module 7	• Using a simple pendulum plot its L-T^2graph and use it to find the effective length of a second’s pendulum • To study variation of time period of a simple pendulum of a given length by taking bobs of same size but different masses and interpret the result • Using a simple pendulum plot its L-T^2graph and use it to calculate the acceleration due to gravity at a particular place

Module 8	• Free vibration natural frequency • Forced vibration • Resonance • To show resonance using a sonometer • To show resonance of sound in air at room temperature using a resonance tube apparatus • Examples of resonance around us
Module 9	• Energy of oscillating source, vibrating source • Propagation of energy • Waves and wave motion • Mechanical and electromagnetic waves • Transverse and longitudinal waves • Speed of waves
Module 10	• Displacement relation for a progressive wave • Wave equation • Superposition of waves
Module 11	• Properties of waves • Reflection • Reflection of mechanical wave at i)rigid and ii)non-rigid boundary • Refraction of waves • Diffraction
Module 12	• Special cases of superposition of waves • Standing waves • Nodes and antinodes • Standing waves in strings • Fundamental and overtones • Relation between fundamental mode and overtone frequencies, harmonics • To study the relation between frequency and length of a given wire under constant tension using sonometer • To study the relation between the length of a given wire and tension for constant frequency using a sonometer
Module13	• Standing waves in pipes closed at one end, • Standing waves in pipes open at both ends • Fundamental and overtones • Relation between fundamental mode and overtone frequencies • Harmonics

Module 14	• **Beats** • **Beat frequency** • **Frequency of beat** • **Application of beats**
Module 15	• **Doppler effect** • **Application of Doppler effect**

MODULE 7

3. WORDS YOU MUST KNOW

Let us remember the words we have been using in our study of this physics course

- Displacement the distance an object has moved from its starting position moves in a particular direction.SI unit: m, this can be zero, positive or negative
  For a vibration or oscillation, thedisplacement could ne mechanical, electrical magnetic. mechanical displacement can be angular or linear.

- Acceleration- time graph: graph showing change in velocity with time , this graph can be obtained from position time graphs
- Instantaneous velocity
  Velocity at any instant of time

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

- Instantaneous acceleration
  Acceleration at any instant of time

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d^2x}{dt^2}$$

- kinematics study of motion without considering the cause of motion
  - **Oscillation: one complete to and fro motion about the mean position** *Oscillation* refers to any periodic motion of a body moving about the equilibrium position and repeats itself over and over for a period of time.
  - **Vibration:** It is a to and fro motion about a mean position. the periodic time is small. so we can say oscillations with small periodic time are called vibrations. the displacement from the mean position is also small.
  - **Frequency:** The number of vibrations / oscillations in unit time.

- **Angular frequency:** a measure of the *frequency* of an object varying sinusoidally equal to 2π times the *frequency* in cycles per second and expressed in radians per second.
- **Inertia:** *Inertia* is the tendency of an object in motion to remain in motion, or an object at rest to remain at rest unless acted upon by a force.
- **Sinusoidal:** **like a sin $\boldsymbol{\theta}$ $\boldsymbol{vs\theta}$** A sine wave or sinusoid is a curve that describes a smooth periodic oscillation.
- **Simple harmonic motion (SHM):**repetitive movement back and forth about am equilibrium(mean) position, so that the maximum displacement on one side of this position is equal to the maximum displacement on the other side. The time interval of each complete vibration is the same.
- **Harmonic oscillator:** A *harmonic oscillator* is a *physical* system that, when displaced from equilibrium, experiences a restoring force proportional to the displacement.
- **Mechanical energy:**is the sum of potential **energy** and kinetic **energy**. It is the **energy** associated with the motion and position of an object.
- **Restoring force:** is a *force* exerted on a body or a system that tends to move it towards an equilibrium state.
- **Conservative force:** is a *force* with the property that the total work done in moving a particle between two points is independent of the taken path. When an object moves from one location to another, the *force* changes the potential energy of the object by an amount that does not depend on the path taken.
- **Bob:**A *bob* is the weight on the end of a pendulum
- **Periodic motion:** **motion** repeated in equal intervals of time.
- Simple pendulum: If a heavy point-mass is suspended by a *weightless*, inextensible and perfectly flexible string from a rigid support, then this arrangement is called a 'simple pendulum'
- **Time period of a pendulum**$T = 2\pi\sqrt{\frac{l}{g}}$
- **Restoring Force**: No net force acts upon a vibrating particle in its equilibrium position. Hence, the particle can remain at rest in the equilibrium position. When it is displaced from its equilibrium position, then a periodic force acts upon it which is always directed towards the equilibrium position. This is called the 'restoring force'. The spring gets stretched and, due to elasticity, exerts a restoring force F on the body directed towards its original position. By Hooke's law, the force F is given by

$$F = -kx,$$

Displacement Equation of SHM:

$$y = a \sin \omega t$$

Time period: The time taken by an oscillating system to complete one oscillation,

$$T = 2\pi/\omega.$$

Frequency: The number of oscillations in one second is called the 'frequency' (n) of oscillation system.

$$n = \frac{1}{T} = \frac{\omega}{2\pi}$$

Phase: When a particle vibrates, its position and direction of motion vary with time. The general equation of displacement is

$$y = a\sin(\omega t + \phi),$$

ϕ is called the 'initial phase' we usually we have $\phi = 0$ when we are talking about the SHM of a single particle.

Velocity in SHM: v in terms of **a** and $\boldsymbol{y}$ as

$$v = \omega\sqrt{a^2 - y^2}$$

Acceleration in SHM: Acceleration of a moving particle is

$\therefore\ \alpha = -\left(\frac{v^2}{a^2}\right)y.$ or $\alpha = -\omega^2 y.$

4. INTRODUCTION:

We have learnt about a simple pendulum, nature of simple harmonic motion. we have understood that a restoring force must set up in any system so that it can oscillate.

We will now learn more about the experiments we perform in the laboratory using a simple pendulum.

5. USING A SIMPLE PENDULUM PLOT L – T AND L – T^2 GRAPHS, HENCE FIND THE EFFECTIVE LENGTH OF SECOND'S PENDULUM USING APPROPRIATE GRAPH.

The apparatus required to perform the experiment is

- **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. As the names suggest, these have the provision to start or stop their working as desired by the experimenter.

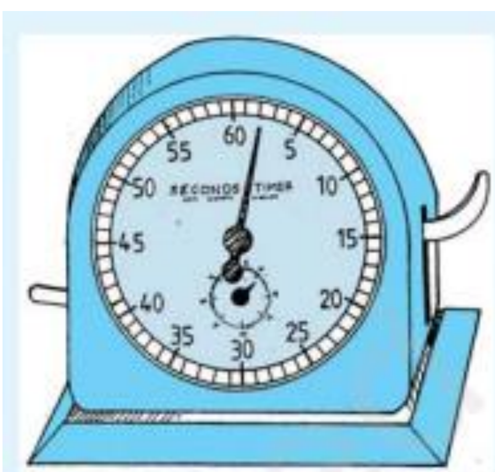
(a) Stop-Watch

- A stop-watch is a special kind of watch. It has a multipurpose knob or button

(B) for start/stop/back to zero position

- 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**.
- If 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.**

(b) **Stop-Clock**

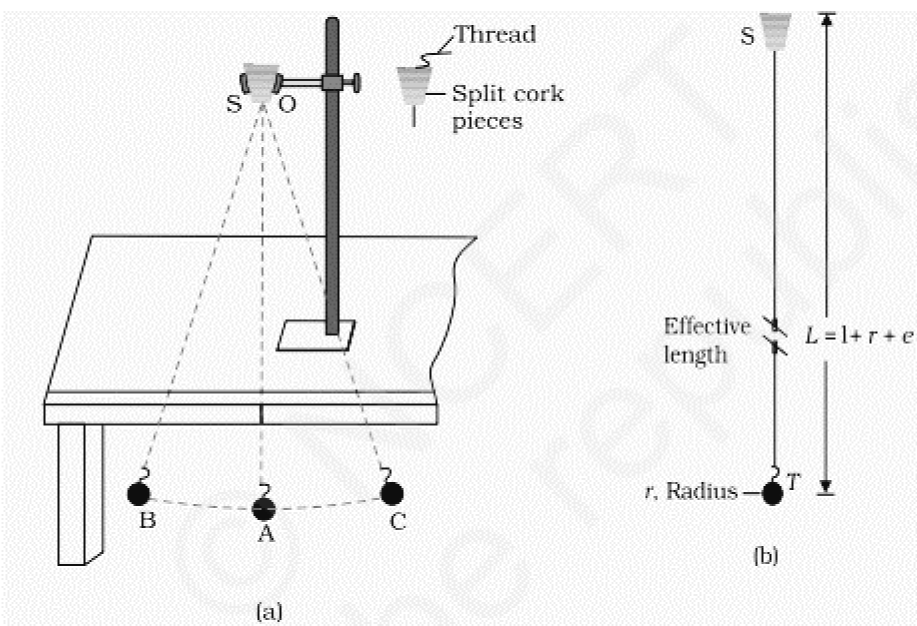


- The least count of a stop-watch is generally about 0.1s
- While **the least count of a stop-clock is 1s**, so for more accurate measurement of time intervals in a school laboratory, a stop-watch is preferred.
- **Digital stop-watches** are also available now. These watches may be started by pressing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

TERMS AND DEFINITIONS

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.

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. **This a good approximation to an ideal simple pendulum.**



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, refer to figure (b)

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

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

Where

L is the length of the pendulum

g is the acceleration due to gravity at the place of experiment.

PROCEDURE

(i) 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.

The string should be tied first, the length of the string along with the hook may be marked with a pen.

(ii) 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

The string should be placed between the split corks. Place the cork between the clamp holders,pull the string up to the pen mark and tighten the clamp holder. The point of suspension should be neat.

(iii) 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**

(iv) Displace the bob to one side, not more than 15^0 angulardisplacements, 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

a) spin about its own axis, or

b) move up and down while oscillating, or

c) revolve in an elliptic path around its mean position.

(v) 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.

You can also choose an extreme position to start counting, start with zero and the pendulum completes one oscillation when it returns to the same extreme position.

(vi) 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.

(vii) **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.

(viii) Record observations in the tabular form with proper units and significant figures.

(ix) Take effective length L along x-axis and T^2 (or T) along y-axis, using the observed values from the table.

Choose suitable scales on these axes to **represent L and T^2 (or T).**

- **Plot a graph between L and T^2**
- **Plot a graph between L and T**

What are the shapes of L –T^2 graph and L –T or T- L (showing the dependence of T on effective length L of the pendulum)graph?
Explain their shapes with reasons

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

OBSERVATION TABLE

Measuring the time period T and effective length L of the simple pendulum

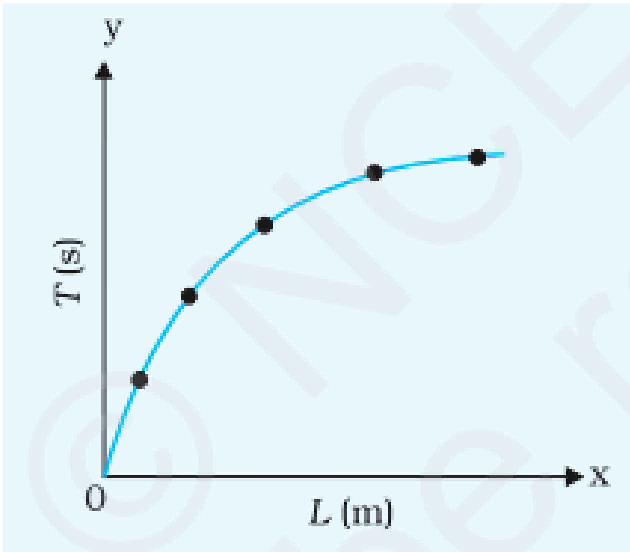
S. No.	Length of the string from the top of the bob to the point of suspension *l*	Effective length, *L* = (*l*+*r*+*e*)		Number of oscillations counted, *n*	Time for *n* oscillations *t* (s)				Time period *T* (= *t*/ *n*)
		(cm)	m		(i)...	(ii)	(iii)	Mean *t* (s)	s

PLOTTING GRAPH

(i) T vs L graphs

Plot a graph between T versus L from observations recorded in the table taking L along x-axis and T along y-axis.

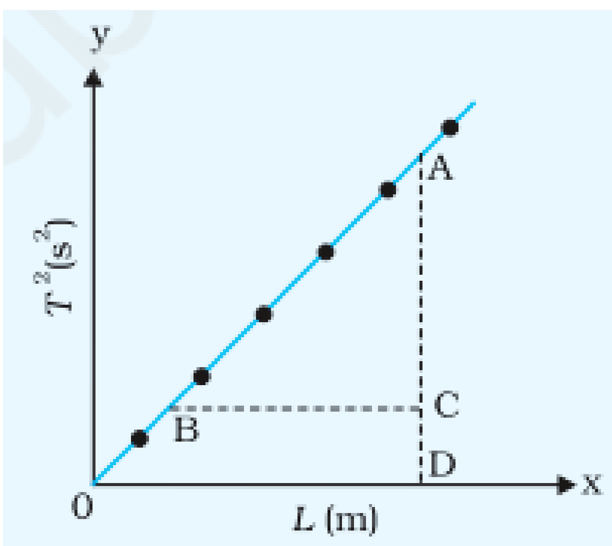
You will find that this graph is a curve, which is part of a parabola



(ii) **L vs T ^{2} graph**

Plot a graph between L versus T^2 from observations recorded in Table taking L along x-axis and T^2 along y-axis.

You will find that the graph is a straight line passing through origin



From the T^2 versus L graph locate the effective length of second's pendulum for

$$T^2 = 4s^2$$

RESULT

- The graph L versus T is curved, convex upwards.
- The graph L versus T^2 is a straight line.
- 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,

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.

TRY THIS

Use the readings below. Assume length of the pendulum to be the effective length (length of thread+ length of hook + radius of the bob)

S No	L (cm)	T = 20 obs	T = T/20 (s)	L/T^2 (cm/s²)	T^2 (s²)
1	80	36	1.8	24.6	3.24
2	90	38.5	1.92	24.4	3.68
3	100	41	2.05	23.80	4.20
4	110	42	2.10	24.94	4.41
5	120	44	2.20	24.79	4.84

$$\text{mean} = \frac{24.6 + 24.4 + 23.8 + 24.94 + 24.79}{5} = \frac{122.53}{5} = 24.5\ \text{cm/s}^2$$

a) Plot a graph between L and T
b) Plot a graph between L and T^2
c) from the graph find the length of a second/s pendulum
d) calculate the value of acceleration due to gravity at the place where the readings are taken
e) Find the length of a pendulum whose period time is 1.5 s.

THINK ABOUT THESE

- 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, a small uncertainty in the measurement of T would result in appreciable error in T^2, hence significantly affecting the result. **A stop-watch with accuracy of 0.1s may be preferred over a less accurate stop-watch/clock.**
- 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.
- 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.
- To suspend the bob from the rigid support, use a 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.**
- The simple pendulum swings to and fro in SHM about the mean, equilibrium position. the relation between T and L

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

g, holds strictly true for small amplitude or swing θ of the pendulum. **Remember that this relation is based on the assumption that sin θ ≈ θ, (expressed in radian) holds only for small angular displacement θ.**

- **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).**

EXAMPLE

Interpret the graphs between L and T ^{2}, that you have drawn for a simple pendulum.

SOLUTION

$$\mathbf{T = 2\pi \sqrt{\frac{l}{g}}}$$

$$\mathbf{T^2 = \frac{4\pi^2 l}{g}}$$

Taking
l,along x-axis and
T ^{2} **along y-axis.**

We will find that the graph is **a straight line passing through origin**

The equation of this line graph will **be y = mx**

$$\mathbf{T^2 = \frac{4\pi^2 l}{g}}$$

The **slope of the l -T^2 graph** is

$$\mathbf{\frac{4\pi^2}{g}}$$

EXAMPLE

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

SOLUTION

We can calculate ‘g’ from the slope

$$\mathbf{slope = \frac{4\pi^2}{g} \text{ or } \qquad g = \frac{4\pi^2}{slope}}$$

6. TO DETERMINE 'g', THE ACCELERATION DUE TO GRAVITY, AT A GIVEN PLACE, FROM THE L – T ^{2} GRAPH, FOR A SIMPLE PENDULUM.

Same as above

EXAMPLE

How will the values change if the experiment was performed at a location on mount Everest? Height of Mount Everest = 8,848 m

https://upload.wikimedia.org/wikipedia/commons/d/d1/Mount_Everest_as_seen_from_Drukair2_PLW_edit.jpg

a) **Length of the pendulum**

b) **Time for 20 oscillations**

c) **Amplitude**

d) **Periodic time**

e) **Slope of L-T^2 graph**

SOLUTION

a) no change

b) increase

c) no change

d) increase

e) As $\mathbf{g = \frac{4\pi^2}{slope}}$ **g decreases with altitude , hence slope must increase**

7. STUDY VARIATION OF TIME PERIOD OF A SIMPLE PENDULUM OF A GIVEN LENGTH BY TAKING BOBS OF SAME SIZE BUT DIFFERENT MASSES AND INTERPRET THE RESULT

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.

8. SOME MORE EXPERIMENTS USING THE SAME APPARATUS

You can also try the following

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.**

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.**

- **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.

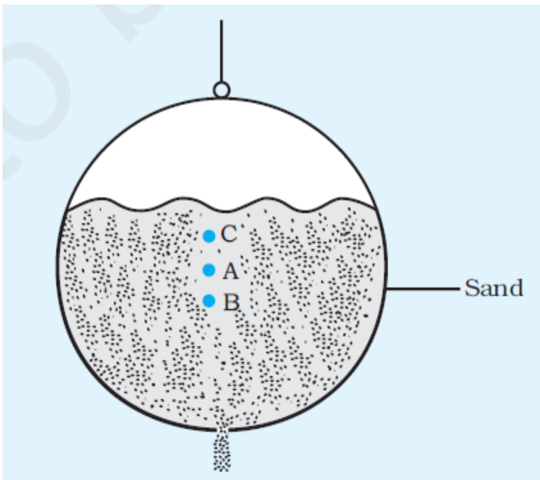
Change the amplitude of oscillation of the bob in small steps of 5° or 10° and determine the time period in each case till the amplitude becomes small (say 5°).

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.**

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)



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.

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 the figure

The CG of bob now goes down to point say A.

The effective length of the pendulum increases and therefore the time period T_A increases

($T_A > Tc$),

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_c again.

9. SUMMARY

- A simple pendulum is a heavy spherical small bob ,with an inextensible thread suspended from a rigid point support
- Simple pendulum executes simple harmonic motion
- The time period is given by

$$\mathbf{T = 2\pi\sqrt{\frac{l}{g}}}$$

- **Time period is independent of mass of the bob**
- **Pendulums keep constant time period and are used as timing devices**
- **Acceleration due to gravity can be experimentally determined using a simple pendulum**