1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 02 (Physics Part 2 ,Class XI)
Module Name/Title	Unit 10, Module 2, Simple Harmonic Motion Chapter14, Oscillations
Module Id	keph_201402_eContent
Pre-requisites	Periodic motion, vibration, pendulum and its oscillatory motion, time period, types of motion, equations of motion, rigid body rotation
Objectives	After going through this module the learners will be able to : • Define Simple harmonic motion • Visualize Ideal simple harmonic oscillator • Understand the term 'Amplitude' • Understand and appreciate the relevance of Phase difference, out of phase, in phase
Keywords	Simple harmonic motion, amplitude, phase, phase difference, out of phase, in phase

2. Development Team

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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**
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)nonrigid 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 2

3. WORDS YOU MUST KNOW

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

- Rigid body: an object for which individual particles continue to be at the same separation over a period of time
- Point object: if the position of an object changes by distances much larger than the dimensions of the body the body may be treated as a point object
- Frame of reference any reference frame the coordinates(x, y, z), which indicate the change in position of object with time
- Inertial frame is a stationary frame of reference or one moving with constant speed
- Observer someone who is observing objects
- Rest a body is said to be at rest if it does not change its position with surroundings
- Motion a body is said to be in motion if it changes its position with respect to its surroundings

- Time elapsed time interval between any two observations of an object

- Motion in one dimension. when the position of an object can be shown by change in any one coordinate out of the three (x, y ,z), also called motion in a straight line
- Motion in two dimension when the position of an object can be shown by changes any two coordinate out of the three (x, y ,z), also called motion in a plane
- Motion in three dimension when the position of an object can be shown by changes in all three coordinate out of the three (x, y ,z)
- Distance travelled the distance an object has moved from its starting position SI unit m, this can be zero, or positive
- 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, the displacement could ne mechanical, electrical magnetic. Mechanical displacement can be angular or linear.
- Path length actual distance is called the path length
- Position time, distance time, displacement time graph these graphs are used for showing at a glance the position, distance travelled or displacement versus time elapsed
- Speed Rate of change of distance is called speed its SI unit is m/s
- Average speed = total path length divided total time taken for the change in position
- Velocity Rate of change of position in a particular direction is called velocity, it can be zero , negative and positive , its SI unit is m/s
- Velocity time graph - graph showing change in velocity with time , this graph can be obtained from position time graphs
- Acceleration Rate of change of speed in a particular direction is called velocity, it can be zero, negative and positive, its SI unit is m/s^2
- 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.
- **Time Period:** Time period is the time needed for one complete vibration
- **Sinusoidal: like a sin θ $vs\theta$.** A sine wave or sinusoid is a curve that describes a smooth periodic oscillation.

4. INTRODUCTION

We come across a number of vibrations and oscillations in daily life. The seat of a cycle or motor cycle vibrates /oscillateswhen we ride over a bump on the road, the spring attached to the seat can be observed as making vibrations**.**

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You may have observed that if we feel a stationary vehicle which has its engine on, or touch the body of a fridge, we feel the vibrations.

You may think of many more examples where you may have experienced or observed the mechanical vibration/oscillation in materials around us.

You are familiar with many examples of repeated motion in your daily life. **If an object returns to its original position a number of times, we call its motion repetitive**. Typical examples of repetitive motion of the human body are heartbeat and breathing. Many objects move in a repetitive way. A swing, a rocking chair, and a clock pendulum are examples. **Here we will consider only those repetitive motions which are necessarily periodic which means the time interval when the motion is repeated is constant**. **So a tree branch swaying in the wind or a boat bobbing in**

river, or a boy on a camel's back or our hands swaying as we walk are not examples of periodic motion, though each one is to and fro about some mean position.

Probably the first understanding the ancients had of repetitive motion grew out of their observations of the motion of the sun and the phases of the moon. Strings undergoing repetitive motion are the physical basis of all stringed musical instruments. What are the common properties of these diverse examples of repetitive motion?

In the previous module you learnt the meaning of the terms frequency, time period, oscillation, vibration, mechanical vibration, and oscillation.

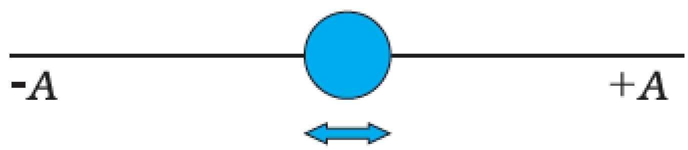
You also plotted a sin θ versus θ graph which shows that the value of sin θ varies periodically between 0 and 1.

Now we will define a special case of an ideal simple harmonic motion.

5. SIMPLE HARMONIC MOTION

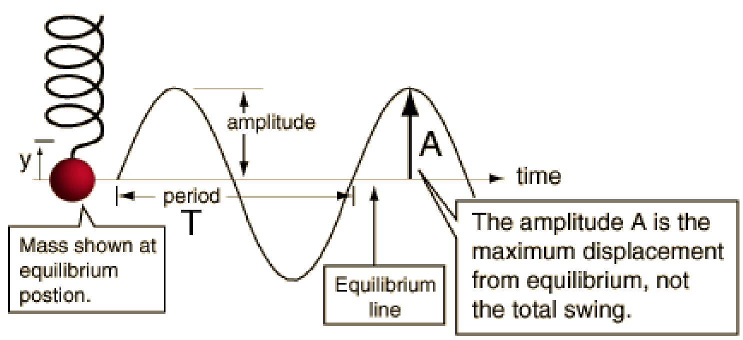
Consider a particle oscillating back and forth about the origin and the limits +A and -A as shown in Fig.

One oscillation refers to displacement from A to O to –A to O to A, this is also called **a cycle.**



A particle vibrating back and forth about the origin of x-axis, between the limits +A and –A

Point O is called the **mean position**. The oscillator moves to and fro about this mean position. **In an ideal case, the displacement O to A is the same as O to –A**



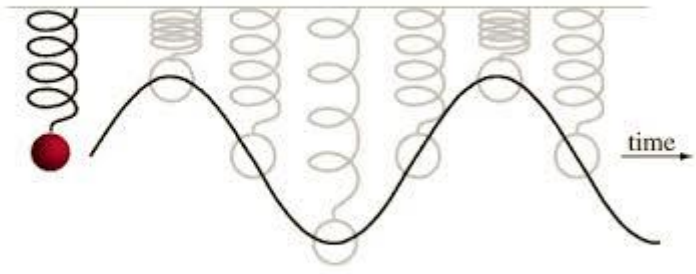
Simple harmonic motion is apparent in **a typical case of mass on a spring**.

When it is subjected to a linear displacement, the motion is sinusoidal in time and demonstrates a single frequency. The amplitude in this case is as marked by A. Keeping the Cartesian co-ordinate system in

mind displacement along horizontal direction is given by x and that in the vertical direction by y.

http://www.physics.louisville.edu/cldavis/phys298/notes/shm_files/image021.gif

If the position is plotted against time, we can connect it with the **sine curve.**



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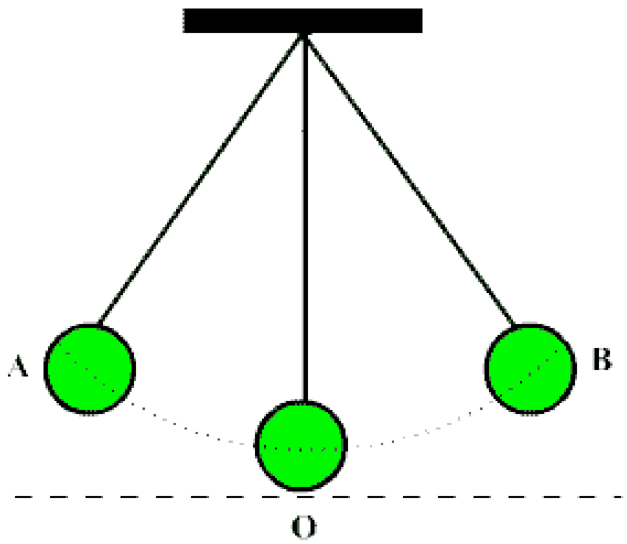
Case of pendulum



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If we displace the **bob of simple pendulum** from its mean position O to a new position A and let it to go it will move towards O under the action of gravity.

The bob will not come to rest at O. Due to i**nertia** it will continue to move towards point B. While moving from point O to B the bob is moving against the gravity.

Its **velocity** continues to **decrease** and **becomes zero** at point B.

The bob will then fall back from B to O under the action of gravity.

Its velocity continues to increases till it becomes maximum at the mean position O. The bob will not stop at O but continue to move towards A due to inertia.

As the bob moves against the gravity from O to A, its velocity decreases and becomes zero at A. The bob will then move from A to O under the action of gravity. The whole process is repeated again and again at the bob continues to vibrate/ oscillate between two extreme positions A and B.

So, the motion of the bob from one extreme position A to other extreme position B and back to position A is called an oscillation.

WHY IS IT CALLED SIMPLE HARMONIC MOTION?

One common characteristic of the motions of the heartbeat, clock pendulum, violin string, is that each motion has a well-defined time interval for each complete cycle. Any motion that repeats itself in equal time is called periodic motion. Its **time period T** is the time required for one cycle of the motion.

Simple harmonic motion is a repetitive movement back and forth through an equilibrium, mean , or central, 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. So there is a rhythm in motion**

The word harmonic implies rhythmic, hence **harmonic motion.**

If the body executes only harmonic motion and all other types of motion are either not there or are being overlooked the body is said to execute **simple harmonic motion.**

Any object can be made to execute simple harmonic motion (SHM) if suitable conditions are applied. you can make a pen move along a straight line path on a table, the same pen can move in curved path, if tied to a string and whirled it could move in a circle, if a torque or a couple is applied it will rotate. If tied to a string it could move like a pendulum and execute simple harmonic motion.

6. AMPLITUDE:

Amplitude of the pendulum is the **maximum displacement from the mean position**, so displacement OA and OB are amplitudes. During the motion of the pendulum bob, or mass attached to a spring, the bob has variable displacement from the mean or equilibrium position.

Displacement of the bob can be measured in terms of distance or in terms of the angle made by the string with the vertical direction along the mean position.

DO YOU THINK the mass would vibrate if **it were not** attached to a spring, or the bob attached to a thread is not suspended from a rigid support?

7. PHASE

The oscillating particle changes its position with respect to the mean position continuously during oscillation.

When a particle oscillates or vibrates both its position and likely direction of motion changes with time. The value of these quantities is unique at any instant of time during one oscillation.

The physical quantity which completely expresses both the position and the likely direction of motion of the vibrating particle at any instant is called phase of the vibrating particle at that instant.

The phase is expressed in terms of ∅ or in terms of periodic time T.

For example, when the particle has only completed ¼ cycle, its phase is $\frac{\pi}{2}$ radian or T/4. The full oscillation being associated with angle $2\pi\ radians$, or a time T.

SAME PHASE OR IN PHASE

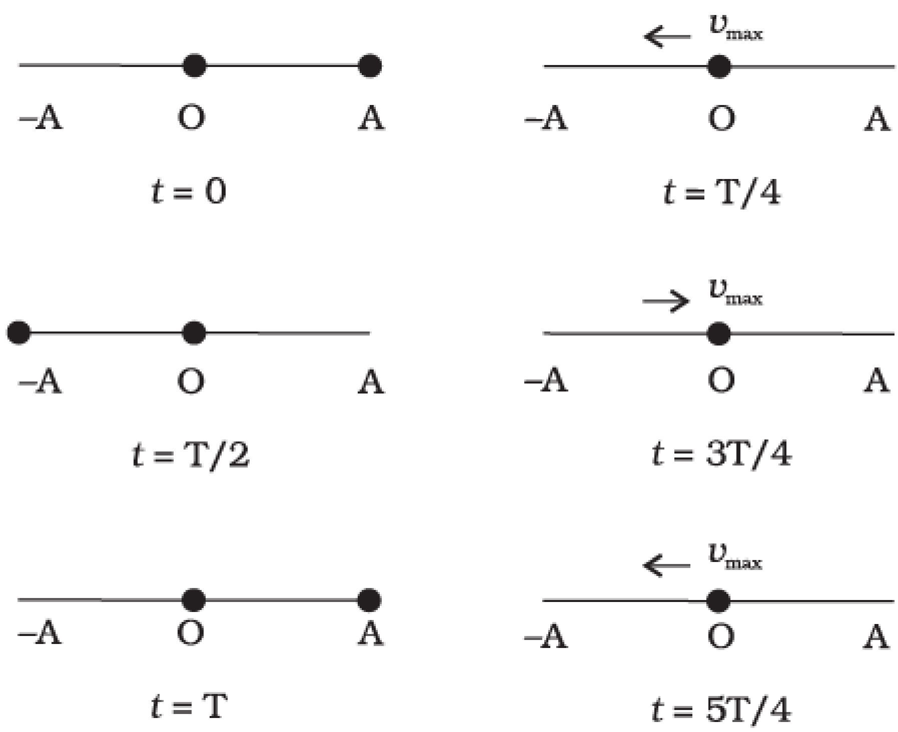
If at any instant two vibrating particles are passing simultaneously through equilibrium positions in the same direction, then they are said to be in the same phase or are in phase.

The moving arms of a marching squad on republic day parade are in phase.

OPPOSITE PHASE

If at any instant two vibrating particles are passing simultaneously through equilibrium positions in the opposite direction then they are said to be in the opposite phase or have a phase difference of π.

If the particle is in extreme position moving towards the mean position, the phase when it moves from A towards O is opposite to when it moves from -A to O.



The location of the particle in SHM at the discrete values t = 0, T/4, T/2, 3T/4, T, 5T/4. The time after which motion repeats itself is T. T will remain fixed, no matter what location you choose as the initial (t = 0) location. The speed is maximum for zero displacement (at x = 0) and zero at the extremes of motion

INITIAL PHASE

A particle may commence its oscillation with a certain displacement, meaning the first observed cycle does not start at either the mean position or at the extreme position. The particle is said to have initial phase. *T*he initial phase is represented by $\emptyset_{\mathbf{0}}$

The value of initial phase is the choice of the location at t = 0

OUT OF PHASE

If at any instant two vibrating particles have no relation in terms of position and likely direction of motion, they are said to be out of phase.

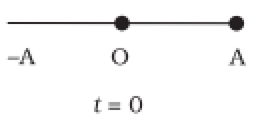
PHASE CHANGE

We find that with the passage of time, the particle repeats its position at multiples of 2π i.e. at intervals of $4\,\pi, 6\pi, 8\pi \ldots$.the particle has the same phase.

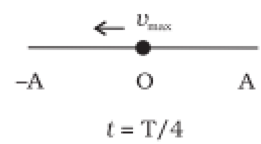
EXAMPLE

Observe the position of the dot in (i) and (ii) and identify the phase relation

a)

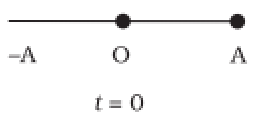


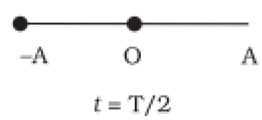
(i)



(ii)

b)

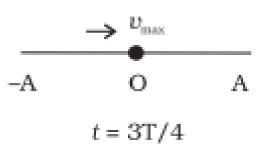




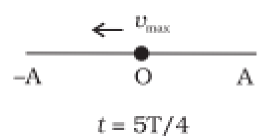
(i) (ii)

c)

(i)



(ii)



SOLUTION

a) (ii) ahead of (i) by $\frac{\pi}{4}$
b) (ii) ahead of (i) by $\frac{\pi}{2}$
c) (i) ahead of (ii) by $\frac{\pi}{2}$

EXAMPLE

A particle is executing simple harmonic motion. It's time period is 2s, what will be the phase of the particle after

i) 3s, ii) 20s

SOLUTION

π, 0

8. SUMMARY

You have learnt in this module

- **Simple harmonic motion: An oscillator is said to execute simple harmonic motion if the displacement on either side of the mean position is the same and it takes the same periodic time for each oscillation.**
- **Amplitude: is the maximum displacement from the mean position.**
- **Phase indicates the position and likely direction of motion of a particle in simple harmonic motion.**