Unit IV – Oscillations, Waves and Sounds

4.1 OSCILLATIONS

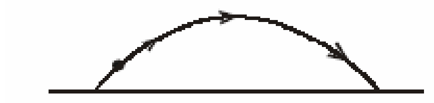
We come across various types of motions in our daily life. Some of them are non-repetitive and some are repetitive.

Non-repetitive motion : The motion which does not repeat itself in time is called a *non-repetitive motion.*

Examples :

(a) **Rectilinear motion** : In this motion, the body moves along a straight line in a specific direction.

(b) **The motion of a projectile** : A projectile moves along a parabolic path.



Note: A projectile is a body thrown into space with certain velocity, making certain angle with the horizontal.

Repetitive motion or periodic motion :

The motion which repeats at regular intervals of time is called *repetitive motion.*
This is also called *periodic motion.*

a) The motion of leaves and branches of a tree in breeze : In this case, leaves and branches move back and forth repeatedly.
b) The motion of a pendulum in a wall clock.
c) The motion of planets in the solar system.

Types of Repetitive Motion or (Periodic Motion) :

They are classified into two types. One is rotatory motion and other is *oscillatory motion.*

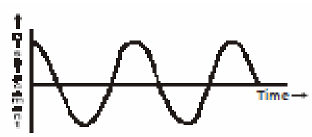
Rotatory Motion :

The motion of planets, blades of a fan, giant wheel and spinning of a top represent *rotatory motion.*

Oscillatory motion :

The motion in which the body moves to and fro repeatedly about its mean position is called *oscillatory motion.*

a) A ball placed in a bowl will be in equilibrium position. If it is displaced a little from its equilibrium position, it will perform oscillations.

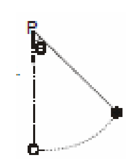


b) The motion of a boat tossing up and down in a river.
c) The motion of a swinging swing.
d) The motion of a pendulum in a wall clock.
e) The motion of air molecules in propagation of sound.

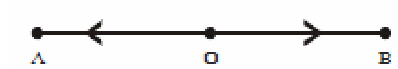
Note : In your house-hold electric service, the voltage and current vary periodically in time. This is also a periodic motion.

Displacement, amplitude, frequency and period of oscillations.

Displacement of an oscillating body : It is the displacement of an oscillating body from its mean position.
It is also defined as change in the position vector of an oscillating body.
For an oscillating simple pendulum, the angle made by the pendulum with the vertical is regarded as angular displacement.



Amplitude : Amplitude of an oscillating body is defined as the magnitude of maximum displacement of the body from its mean position. Suppose a body is oscillating between A and B with the mean position O. Then amplitude is OA or OB.



In the case of simple pendulum, it is the small angle from the vertical through which simple pendulum is displaced from its mean position or equilibrium position.

One oscillation : One complete to and fro motion of the oscillating body is called one oscillation.

Frequency : It is the number of oscillation made by the body in one second.

Period : It is the time taken by a body to complete one oscillation.

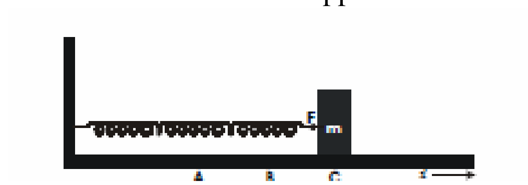
Mean Position or Equilibrium Position : It is a position of the body when the net force acting on it is zero.

Phase of a particle in oscillatory motion :This represents the state of vibration of the particle at a given time. From phase, we can know where the particle is and in which direction it is moving or about to move with respect to its mean position.

Oscillations in springs - Simple Harmonic Motion.

Consider a block of mass ‘m’ fixed to a spring which in turn is fixed to a rigid wall as shown in the figure. The block is placed on a frictionless horizontal surface. If the block is pulled on one side and is released, it executes to and fro motion about its mean position. Here B represents mean position. A and C represent maximum displacement positions.

When the spring is deformed, there arrises an internal force in the spring which tries to bring the spring to its original shape. Such force is called a restoring force. Here the restoring force is directly proportional to displacement of the block and acts in opposite direction.



Mean
Position
$F \propto -x$

Such motion is called *simple harmonic motion.*

In the case of simple hormonic motion, displacement can be represented by means of sine function,

$y = a \sin\omega t$

where a = amplitude, ωt = *phase.*

Other examples : a) Simple pendulum slightly pushed to one side executes S.H.M.
b) Atoms or molecules in a solid execute S.H.M.

CLASSIFICATION OF OSCILLATIONS

They are classified into free oscillations, damped oscillations and forced oscillations.

Free Oscillations : Suppose a body capable of oscillations is displaced from its mean position and left free to itself. It oscillates with a definite frequency and amplitude.

These oscillations are called *free oscillations* and the definite frequency is called *natural frequency* of the body. Here we assume absence of frictional forces. Hence these oscillations are idealised oscillations.(not real). Amplitude is always constant in free oscillations

Displacement

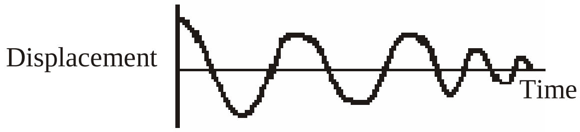
Time

Note : In case of simple pendulum, natural frequency depends upon length of the pendulum and acceleration due to gravity.

Simple Pendulum : It is a very small heavy metal bob suspended at a point from a firmly fixed support using a single strand thread so that it oscillates freely. The distance between the point of suspension and centre of bob is called length of the pendulum.

Second's Pendulum : It is simple pendulum of time period two seconds.

Damped Oscillations : Suppose a simple pendulum is put into oscillation. Here air drag and friction at support oppose oscillations of the pendulum and dissipate energy of pendulum gradually. Then pendulum makes oscillations with decreasing amplitude. Such oscillations are called *damped oscillations*. At one point of time, energy of the pendulum is totally dissipated. As a result pendulum comes to rest.

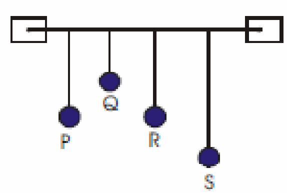


Other examples : Oscillations of a swing, oscillations of a stretched string.

Forced Oscillations : Suppose a child is in swinging swing. Mechanical energy of swing decreases because of internal as well as external frictional forces. As a result amplitude of swinging decreases gradually and the system ultimately comes to a halt. With the help of appropriately timed pushes, the swinging can be sustained and its amplitude can be increased. Oscillations made by the swing under these conditions are called *forced or driven oscillations.*

When the frequncy of appropriately timed pushes is equal to natural frequency of the swing, there is a dramatic increase in the amplitude. This is called ***resonance***.

Example-1 : Pendula of different lengths are suspended from a string. They are P, Q, R and S. P and R having same length, have same natural frequency. If P is set swinging, others are forced to oscillate because they are coupled by stretched string. Here R will oscillate with greatest amplitude due to resonance.



Example - 2 : Tacoma Narrows Bridge in Washington state (USA) collapsed in 1940 because of resonant vibrations. Winds blowing on that occasion through the bridge set vibrations in bridge at a frequency near the natural frequency of the bridge. Then the bridge oscillated with large amplitude. As a result, the bridge collapsed.

Questions :

1. What is a repetitive motion? Give an example.
2. What is an oscillatory motion ? Give an example.
3. What is the mean or equilibrium position of an oscillating body.
4. Define amplitude, time period and frequency of oscillations.
5. Define a phase of particle in oscillatory motion.
6. What are free oscillations ?
7. What are damped Oscillations ? Give an example.
8. What are forced oscillations ?
9. What is a resonance ?
10. A particle takes 20s to make 10 oscillations. Calculate time period and frequency.
11. The Oscillations of a particle is given by $y = 10 \sin\omega t$ where displacement Y is in metre. Find the amplitude.

Answers

1. The motion which repeats at regular intervals of time is called repetitive motion. *Example :* the motion of a pendulum in a wall clock.

2. The motion in which the body moves to and fro repeatedly about its mean position is called oscillatory motion. *Example :* The motion of a boat tossing up and down in a river.

3. Equilibrium position of an oscillating body is the position of the body when the net force acting on it is zero.

4. *Amplitude :* It is defined as the magnitude of the maximum displacement of the body from its mean position.

Time period : It is the time taken by the body to complete one oscillation.

Frequency : It is the number of oscillations made by the body in one second.

5. Phase is the state of vibration of a particle at given instant of time.

6. They are oscillations made by a body when it is left free to itself.

7. Oscillations of a simple pendulum are opposed by air drag and friction at its support. As a result pendulum makes oscillations with decreasing amplitude. Such oscillations are called damped oscillations.

8. Oscillations of a pendulum die out in course of time due to internal and external frictional forces. But they can be sustained with the help of an appropriate external force. Such oscillations are called forced oscillations.

9. It is the condition in which the frequency of the appropriate external force is equal to the natural frequency of the body at which the body oscillates with large amplitude.

10. $$\text{Period} = \frac{\text{Time taken by the particle}}{\text{Number of oscillations made by the particle}}$$

$$= \frac{20}{10} = 2S$$

$$\text{Frequency} = \frac{1}{\text{Period}} = \frac{1}{2} = 0.5\text{Hz}.$$

11. We know y = a sin wt

Here y = 10 sin wt

$\therefore$ a = 10 m