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 1, Periodic motion Chapter14, Oscillations
Module Id	keph_201401_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 the module the learner will be able to : • Understand the characteristics of periodic motion • Explain the terms oscillator, time period, frequency, amplitude, mean position • Know about mechanical and non-mechanical periodic physical quantities
Keywords	Frequency, periodic motion, oscillation , vibration, mean position, displacement, amplitude, mechanical periodic motion , non-mechanical periodic physical quantity

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, to and fro motion about a mean position** • **Mechanical and non-mechanical periodic physical quantities** • **Periodically varying 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 for an oscillator • 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 1

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. Its SI unit is 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
- 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

4. INTRODUCTION

In our daily life we come across various kinds of motions.

You have already learnt about some of them, e.g**. rectilinear motion –motion in a straight line, and motion in a plane - motion of a projectile**.

Both these motions are non-repetitive. We also considered **motion in a circle and rotation of a rigid body about a fixed axis.**

We have also learnt about uniform circular motion and orbital motion of planets in the solar system. In these cases, the motion is **repeated after a certain interval of time**, that is, the motion is **periodic.**

In your childhood you must have enjoyed swinging on a swing or going round on a merry go round. Both these motions are **repetitive** in nature but in different ways. Both are **periodic motions,** merry go round being like a planet moving round the sun and the swing moving to and fro about a mean position.

Examples of such periodic to and fro motions are many:

- Oscillating springs
- A swing door
- A boat tossing up and down in a river,
- The piston in an engine going back and forth, etc.

A periodic to and fro motion is termed as **oscillatory motion or vibratory motion. How are they different? Usually vibration is associated with small displacements and oscillation with larger displacements. The wings of a bee or a mosquito vibrate, while a swing oscillate**

https://publicdomainvectors.org/en/free-clipart/Swing-on-a-tree/84084.html

https://upload.wikimedia.org/wikipedia/commons/thumb/8/8e/Bees-wings.web.jpg/120px-Bees-wings.web.jpg

In this unit, we will study oscillatory motion.

The study of oscillatory motion is basic to physics; its concepts are required for the understanding of many physical phenomena. In musical instruments, like the sitar, the guitar or the violin, we come across vibrating strings that produce pleasing sounds. The membranes in drums and diaphragms in larynx and speaker systems vibrate to and fro about their mean positions. The vibrations of air molecules make the propagation of sound possible.

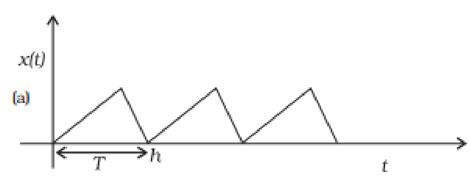
THINK ABOUT THIS

- **What is the difference between the terms oscillation and vibration?**
- **Are they both to and fro motion about a mean position?**
- **Are they both periodic?**
- **What kind of motion is the swaying of a tree branch due to wind? A girl skipping rope?**
- In a solid, the atoms vibrate about their equilibrium positions, the average energy of vibrations being proportional to temperature.
- AC power supply give voltage that oscillates alternately going positive and negative about the mean value (zero).

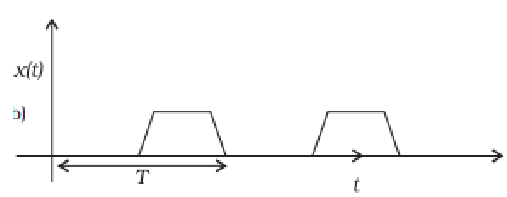
The description of a periodic motion in general and oscillatory motion in particular, requires some fundamental vocabulary to define the concepts like **period, frequency, displacement, amplitude and phase.**

5. PERIODIC AND OSCILLATORY MOTIONS

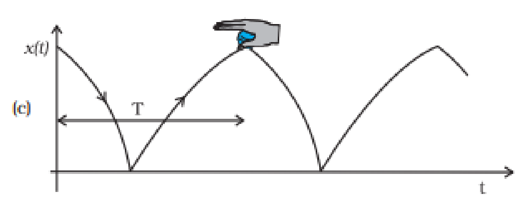
Suppose an insect climbs up a ramp and falls down. It comes back to the initial point and repeats the process identically. If you draw a graph of its height above the ground versus time, it would look something like this.



If an old person climbs up a step, waits a while comes down, waits a while again and repeats the process, its height above the ground plotted against time would look like that in shown here.



When you play the game of bouncing a ball off the ground, between your palm and the ground, its height versus time graph would look like the one shown here.



Note that both the curved parts in figure of bouncing a ball are sections of a parabola given by the Newton's equation of motion,

$h = ut + \frac{1}{2}gt^2$ for downward motion, and

$h = ut - \frac{1}{2}gt^2$ for upward motion, with different values of u in each case.

These are examples of **periodic motions**. **Thus, a motion that repeats itself at regular intervals of time is called a periodic motion.**

Elastic Systems regain, or tend to regain their original shape and size once the deforming forces are removed, for a system displaced from its lowest potential energy condition tends to come down to minimum potential energy condition

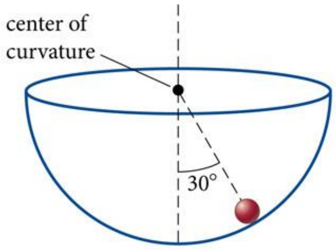
https://www.triganostore.com/media/catalog/product/cache/1/image/9df78eab33525d08d6e5fb8d27136e95/t/r/trampoline-diam-366-m-filet-de-protection-echelle_1.jpg

Very often the body undergoing periodic motion has an **equilibrium position** somewhere inside its path.

When the body is at this position, no net external deforming force acts on it.

Therefore, **if it is left there at rest, it remains there forever**.

If the body is given a small displacement from the equilibrium position, a force comes into play which tries to bring the body back to the equilibrium point, giving rise to oscillations or vibrations. For example, a ball placed in a bowl will be in equilibrium at the bottom. If displaced a little from the point, it will perform oscillations in the bowl.



https://i.stack.imgur.com/xaBfy.jpg

Every oscillatory motion is periodic, but every periodic motion need not be oscillatory.

Continuous circular motion is a periodic motion, but it is not oscillatory.

THINK ABOUT THIS

- **The wings of a flying bird and the wings of a fly**
- **A boy on a merry go round and a boy on a swing**
- **Halley's comet moves around the sun and is observable after every 76 years**
- **Moon completes one revolution around the earth in 27.4 days**

You will learn in the unit

Oscillatory motion arises when the **force on the oscillating body is directly proportional to its displacement from the mean position,** which is also the equilibrium position.

Further, at any point in its oscillation**, this force is directed towards the mean position**. This we will consider later in the unit.

In practice, oscillating bodies eventually come to rest at their equilibrium positions, because of the damping due to friction and other dissipative causes. However, they can be forced to remain oscillating by means of some external periodic agency.

Any material medium can be pictured as a collection of a large number of coupled oscillators. The continuous oscillations of the constituents of a medium one after another manifest themselves as waves. Examples of waves include sound waves, water waves, seismic waves, and waves on strings. **These we will study in detail later**.

6. PERIOD AND FREQUENCY

We have seen that **any motion that repeats itself at regular intervals of time is called periodic motion.**

The smallest interval of time after which the motion is repeated is called its period.

Let us denote the period by the symbol T.

Its S.I. unit is second.

For periodic motions, which are either too fast or too slow on the scale of seconds, other convenient units of time are used. The period of vibrations of a quartz crystal is expressed in units of **microseconds (10^{-6} s)** abbreviated as **μs**.

On the other hand, the orbital period of the planet Mercury is 88 earth days. The Halley's comet appears after every 76 years.

The reciprocal of T gives the number of repetitions that occur per unit time. This quantity is called the **frequency** of the periodic motion. It is represented by the symbol ν or f.

The relation between ν and T is

$\nu = 1/T$

The unit of ν is thus s^{-1}.

As a mark of respect to the discoverer of radio waves, Heinrich Rudolph Hertz (1857-1894), a special name has been given to the unit of frequency. It is called **hertz** (abbreviated as Hz).

Thus, 1 hertz = 1 Hz =1 oscillation per second =$1s^{-1}$

Note, that the frequency, ν, is not necessarily an integer.

EXAMPLE

On an average a human heart is found to beat 75 times in a minute. Calculate its frequency and period.

SOLUTION

The beat frequency of heart = 75/ (1 min) = 75/(60 s) = 1.25 s^{-1} = 1.25 Hz

The time period T = 1/ (1.25 s^{-1}) = **0.8 s**

EXAMPLE

Find the time period and frequency of minute and hour hands of a watch?

SOLUTION

The minute hand has a period of 1 hour and the hour hand has a period of 12 hours

EXAMPLE

Identify periodic motion from among the following:

- **Motion of moon around the earth.(Y,N)**

- **Motion of school bus going from school to pick students and then coming back to the school. .(Y,N)**
- **A plastic ball is floating in a bucket of water it is pushed down and released. .(Y,N)**
- **A branch of a tree swaying in high speed wind. .(Y,N)**
- **A piston in the engine of a car which is moving with constant speed. .(Y,N)**

EXAMPLE

What is the product of frequency and time period?

SOLUTION

Frequency x T = 1

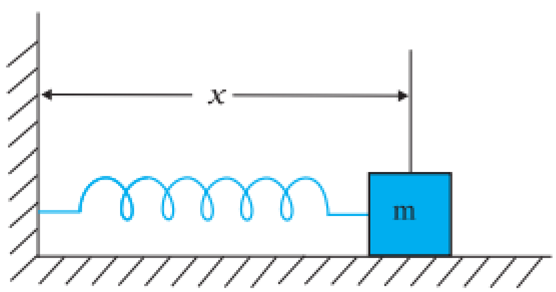
7. DISPLACEMENT

In our previous study on motion, we defined displacement of a particle as the **change in its position vector. This for an object moving in a straight line was just the change in position.**

In the case of rectilinear motion of a steel ball on a surface, the distance from the starting point as a function of time is its **position -displacement**.

The choice of origin or point of reference is a matter of convenience.

Consider a block attached to a spring, the other end of which is fixed to a rigid wall

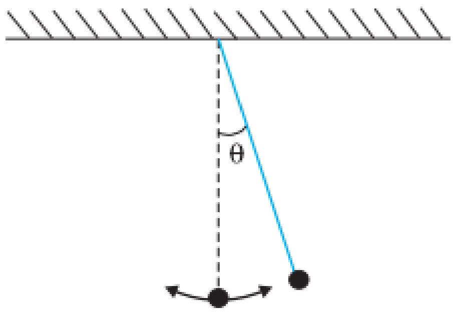


Notice here -A block is attached to a spring, the other end of which is fixed to a rigid wall.

Say the block moves on a frictionless surface. The motion of the block can be described in terms of its distance or displacement ‘x’ from the wall. This, as you can imagine, will be about some mean position.

Set one up for yourself using a spring from a pen

Generally, it is convenient to measure displacement of the body from its **equilibrium position**. For an oscillating simple pendulum, the angle from the vertical as a function of time may be regarded as displacement.

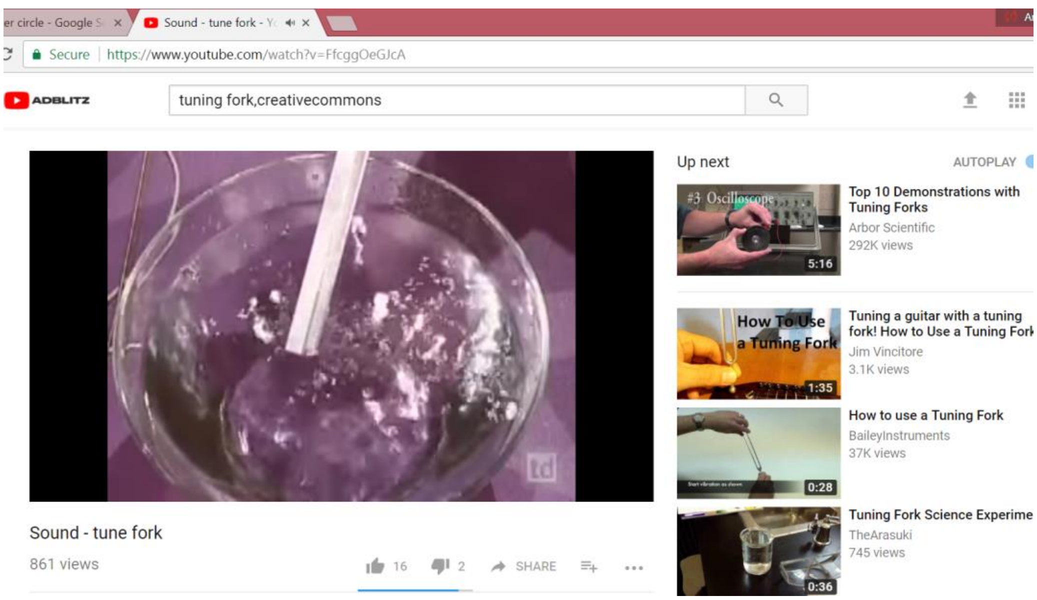


An oscillating simple pendulum; its motion can be described in terms **of angular displacement θ** from the vertical.

Set one up using a heavy object tied with a string

Observe the video to get an idea about vibration, oscillation and mean position

Tuning fork https://www.youtube.com/watch?v=FfcggOeGJcA



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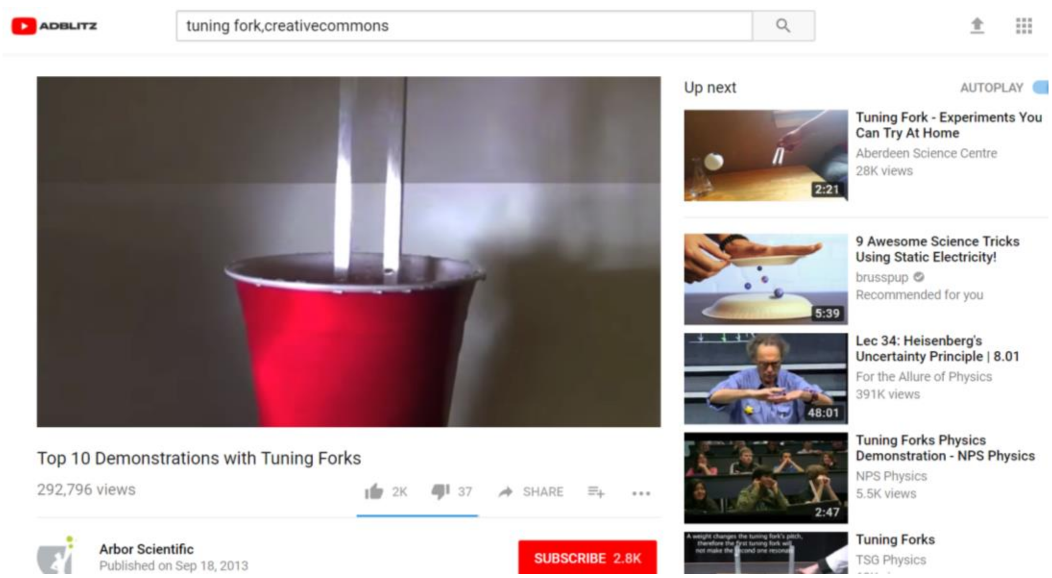

Tie a stone to an inextensible thread. Suspend the thread from a rigid point. Swing the pendulum and look for

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- **mean position,**
- **maximum displacement from the mean position and**
- **One oscillation (displacement from mean position to one extreme, then to the other extreme and back to the mean position.)**

View pendulums attached to clocks

https://www.youtube.com/watch?v=lbzlHqETWdU https://www.youtube.com/watch?v=ogN01I3wZFo

This science experiment attempts to answer the question of whether mass affects the period (number of swings) of a pendulum. You can participate in the experiment by counting the swings of a 3g mass and a 4g mass. See also video on lengths of pendulums:

http://youtu.be/JQbHsR0PkUc

Project Worksheet at http://www.biologycorner.com/workshee...

The term displacement is not always to be referred in the context of change in position only.

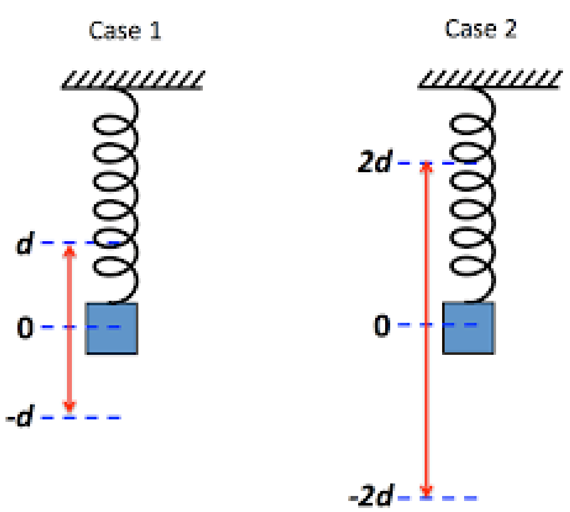
There can be many other kinds of displacement variables.

- **The voltage across a capacitor, changing with time in an a.c. circuit, is also a displacement variable.**
- **In the same way, pressure variations in time in the propagation of sound wave,**
- **The changing electric and magnetic fields in a light wave.**

  These are examples of displacement in different contexts.

The displacement variable may take both positive and negative values.

For example for a particle moving to and fro about a mean position, the mean position may be regarded as the zero on a number line, motion along +y direction to –y direction may be used to show to and fro motion.



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In experiments on oscillations, the displacement is measured at different times. **Or we need equations of motion to describe the position, velocity and acceleration of an oscillating particle at an instant of time. In the above case, the displacement is linear**

TRY THIS

- **Swing your arms as if you are marching. Make your arms go right up to your shoulders. Swing them back and forth.**
- **Identify a mean rest position and displacement.**
- **Why would you call it oscillatory motion?**
- **Is the motion periodic?**
- **Think of conditions when this would be periodic and have a constant periodic time.**
- **Can you determine the frequency?**
- **Swing a pendulum from any rigid support.**
- **What is the difference between swinging of your arms and swinging of a pendulum?**

EXAMPLE

Use the given values for sin, θ varying from 0^0-180^0 at intervals of 15 ^{0}

sin (0°) = 0

sin(15°) = 0.258819

sin(30°) = 0.5

sin(45°) = 0.707107

sin(60°) = 0.866025

sin(75°) = 0.965926

sin(90°) = 1

sin(105°) = 0.965926

sin(120°) = 0.866025

sin(135°) = 0.707107

sin(150°) = 0.5

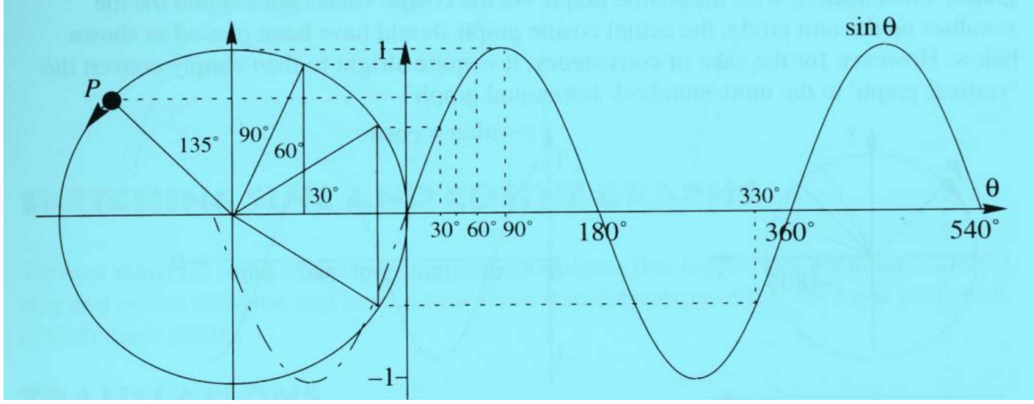
sin(165°) = 0.258819

sin(180°) = 0

Use a graph sheet to plot a graph of sin θ vs. θ.

SOLUTION

θ	0	30	45	60	90	120	135	150	180	. . .	330	360
sin θ°	0.0	0.5	0.71	0.87	1.0	0.86	0.71	0.5	0.0	. . .	–0.5	0.0



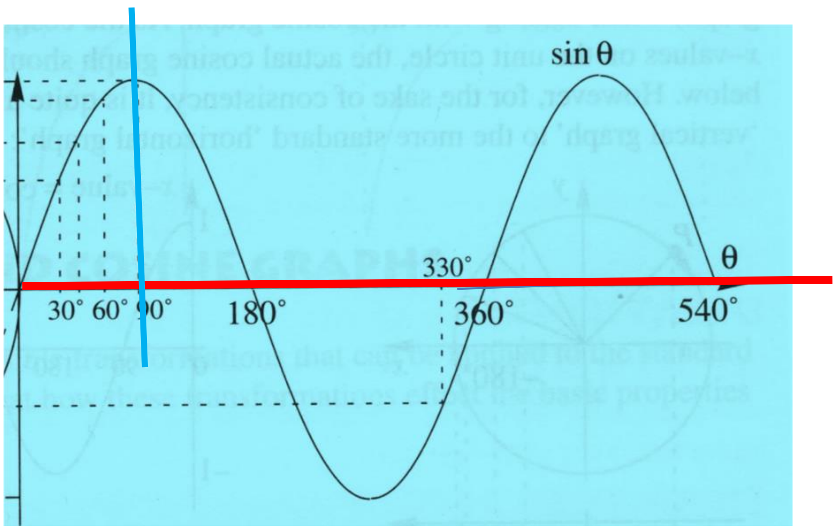
Use the table to plot the sine curve.

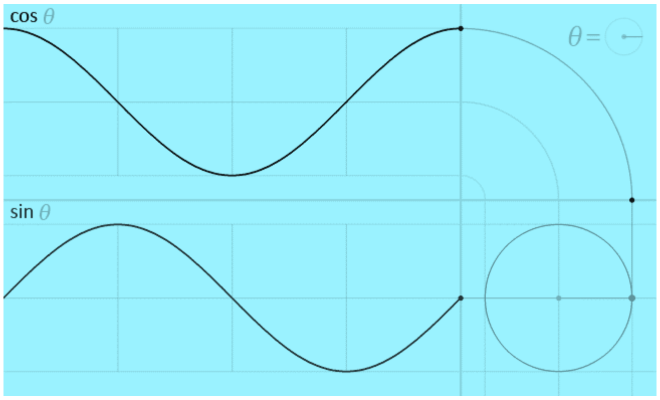
- You could also plot a cosine θ vs θ graph
- These graphs show periodicity and the values of sin and cos repeat after 360^0 or 2π radians.
- The value of sin varies between +1 and -1
- It changes periodically
- **The curve is referred to as sinusoidal curve**

TABLE 1 Values of the Sine and Cosine at Various Angles

degrees	0°	30°	45°	60°	90°	120°
radians	0	$\frac{\pi}{6}$	$\frac{\pi}{4}$	$\frac{\pi}{3}$	$\frac{\pi}{2}$	$\frac{2\pi}{3}$
sin x	0	0.500	0.707	0.866	1	0.866
cos x	1	0.866	0.707	0.500	0	−0.500
degrees	135°	150°	180°	210°	225°	240°
radians	$\frac{3\pi}{4}$	$\frac{5\pi}{6}$	π	$\frac{7\pi}{6}$	$\frac{5\pi}{4}$	$\frac{4\pi}{3}$
sin x	0.707	0.500	0	−0.500	−0.707	−0.866
cos x	−0.707	−0.866	−1	−0.866	−0.707	−0.500

The curve is referred to as sinusoidal curve. It is periodic, as the values will repeat.





https://upload.wikimedia.org/wikipedia/commons/3/3b/Circle_cos_sin.gif

EXAMPLE

Consider any wheel of a car in motion. The wheel turns and the car moves forward or backward.

a) **Is the motion of the wheel periodic?**
b) **Is the motion of the wheel periodic if the car travels with constant speed on a straight road?**
c) **Could there be a relation between frequency of revolution and the speed of the car?**

SOLUTION

a) No, each revolution does not take the same time

b) Yes, it is possible

c) Higher the speed, greater the frequency of revolution

EXAMPLE

A stone tied to the end of a string is whirled in a horizontal direction with constant speed. If the stone makes 14 rev in 25s,

a) Find the time period and frequency.

b) Would the values of periodic time and frequency change if the length of the thread is changed?

c) Can the same stone be made to execute to and fro motion?

SOLUTION

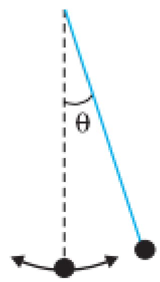
a)

$$\text{time period} = \text{time for one revolution} = \frac{25}{14} = 1.78 \text{ s}$$

$$\text{Frequency} = \frac{1}{T} = \frac{14}{25} = 0.56\ Hz$$

b) No

c) Yes



EXAMPLE

Calculate the time period of a flywheel making 420 revolutions per min.

SOLUTION

Here frequency = 420 revolutions/min

$= \frac{420}{60}$ revolution per sec

Time period $= \frac{60}{420} = 0.14\ s$

8. SUMMARY

In this module you have learnt

- **An object is said to be in periodic motion if it repeats its motion in a fixed time**
- **To and fro motion about a mean position is called oscillatory or vibratory motion**
- **All periodic motion in nature are not necessarily oscillatory or vibratory.**
- **Oscillatory motion by bodies moving due to changes in elastic potential energy is periodic.**
- **The change in position from the mean position is referred to as displacement.**

- **Displacement could be mechanical as in the case of a pendulum or a tuning fork.**
- **Mechanical displacement could be angular displacement or linear displacement**