1. Details of Module and its structure

Subject Name	Physics
Course Name	Physics 02 (Physics Part 2 ,Class XI)
Module Name/Title	Unit 10, Module8,Free forced vibration and resonance Chapter 14, Oscillations
Module Id	keph_201408_eContent
Pre-requisites	Periodic motion, periodic sine and cosine function, simple harmonic motion,phase, energy of a simple harmonic motion, periodic time, frequency Simple Pendulum, dissipation of energy, experiments with simple pendulum
Objectives	After going through this module, the learners will be able to: • Know the meaning of free vibration, natural frequency • forced vibration and resonance • Understand the design of sonometer • Appreciate the resonance tube apparatus • Recognise examples of resonance around us
Keywords	Free vibration, Natural frequency, Damped vibration, Resonance, Dissipation of Energy, sonometer, resonance tube apparatus

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

MODULE 8

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
- **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.
- **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.
- **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 anequilibrium(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'

- 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

$$\therefore\ \alpha = -\left(\frac{v^2}{a^2}\right)y \quad \text{Or} \quad \alpha = -\omega^2 y$$

4. INTRODUCTION

In our observation around us we come across innumerable examples of vibratory motion. Most observable ones are those producing sound. The passage of fly, butterfly, raindrops on a roof etc, as they are detected by our ear. The vibration of a car /bus/truck bonnet, due to running engines can be felt by touching them.

https://upload.wikimedia.org/wikipedia/commons/thumb/1/17/Silver-studded_blue_%28Plebejus_argus%29_female_underside_Bulgaria.jpg/1280px-Silver-studded_blue_%28Plebejus_argus%29_female_underside_Bulgaria.jpg

https://c.pxhere.com/photos/7d/a0/tuning_fork_metal_instrument_sound_frequency_classical_vibrate_physics-946832.jpg!d

In case you have heard the vibrations of a string attached to a musical instrument, the sound from them on plucking is different from one another however the same string produces the same sound in case it is sounded after an interval of time. Tuning forks of different sizes and prong thickness sound different. We can recognise our friends by their speech even when we are not directly facing them.

This is due to the fact that every system has a distinct natural frequency of vibration.

5. FREE VIBRATIONS AND NATURAL FREQUENCY

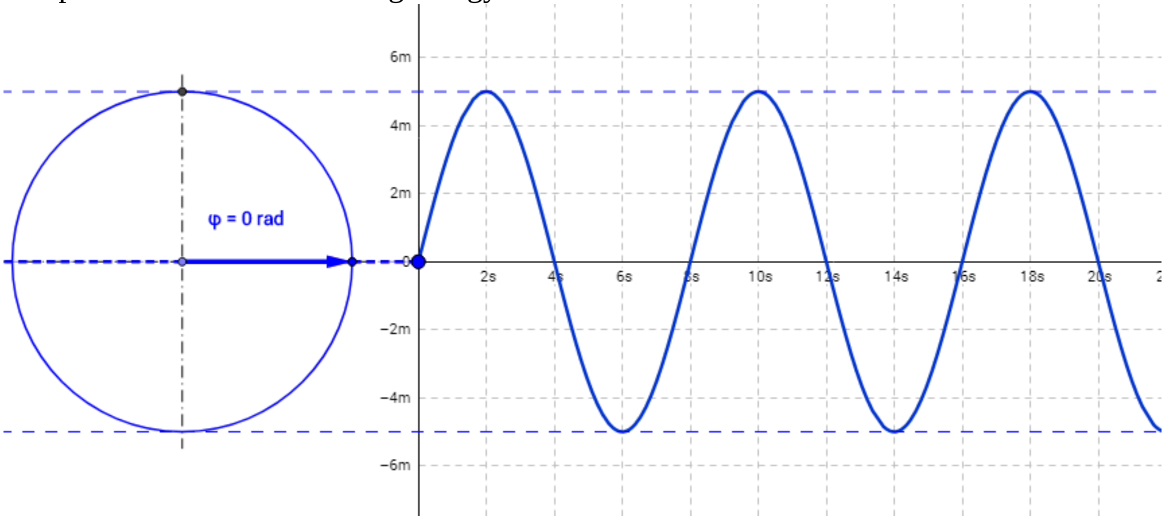
When a body capable of vibration (or oscillation) is displaced from its mean position and then left free, it begins to vibrate with a definite frequency.
This frequency depends upon **the intrinsic properties of the body** such as

- size,
- elasticity,
- mass

and is called the **'natural frequency' of the body**.

Such vibrations of the body which are not being affected by any external dampening force(like friction or any other) are called 'free vibrations'.

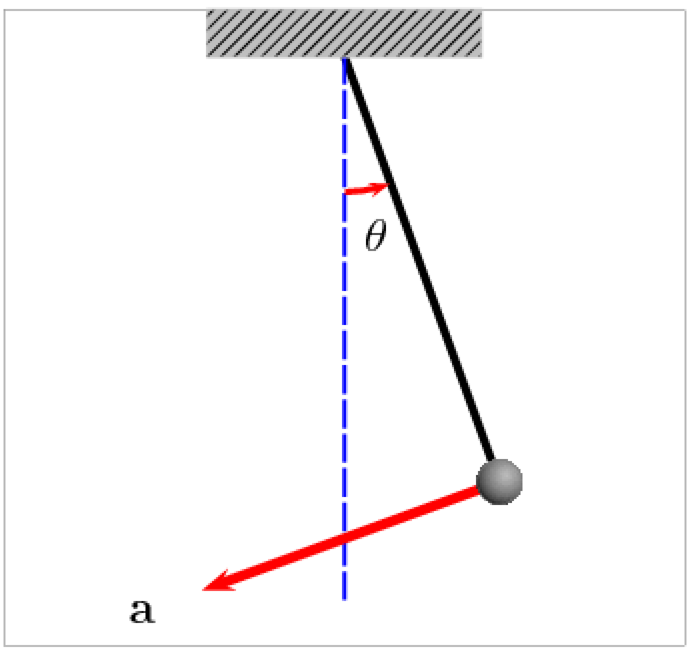
Theoretically, the energy of the body executing free vibrations remains constant and the body is expected to go on oscillating with **'constant' amplitude** infinitely as shown in fig. below. But the damping forces cause the amplitude to decrease continuously till the vibrations stop or else will continue if an external system compensates for the decreasing energy.



Source: Geogebra

Examples:

1) When a bob suspended by a thread is displaced from its equilibrium position and then left free, it oscillates with its natural frequency which depends upon the length of the thread.



https://commons.wikimedia.org/wiki/File:Oscillating_pendulum.gif

2) When a metal gong is struck with another metal /wooden /rubber hammer, then it vibrates with their natural frequency. This frequency depends upon the thickness, size and shape of the gong and the elasticity of its material.

3) If we pluck a sitar wire, it vibrates with its natural frequency which depends upon the length, density and tension of the wire.

https://en.m.wikipedia.org/wiki/File:Sur2.jpg

4) Bridges, high rise buildings, ships, different parts of machines, etc., also have their natural frequencies of oscillation.

However, in all the above examples some damping force is present, due to which the energy given to the body in setting it on vibration is **dissipated continuously**.
Hence, the **amplitude of vibration decreases with time and ultimately the vibrations or oscillations come to a stop**.

For example, during oscillations of the bob of a simple pendulum, the friction of the pivot and the damping force due to the viscosity of air remain present due to which the amplitude of the oscillations of the bob goes on decreasing slowly and ultimately the bob stops.

In reality, free vibrations are impossible in life.

DAMPING AND DAMPED VIBRATIONS

We know that the motion of a simple pendulum, swinging in air, dies out eventually.
Why does it happen?

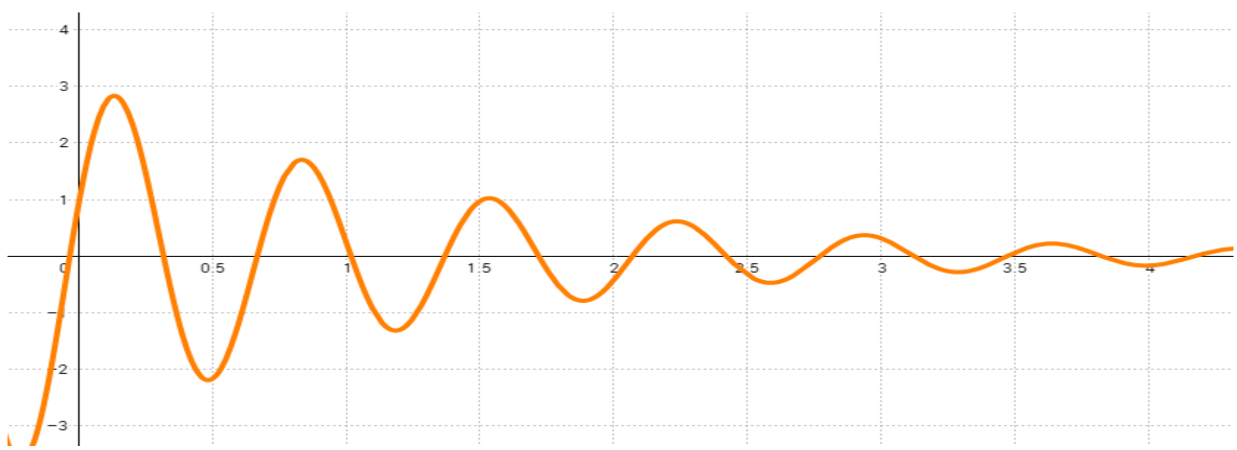
This is because the air drag and the friction at the support oppose the motion of the pendulum and dissipate its energy gradually.

The pendulum is said to execute **damped oscillations**.

In damped oscillations, the energyof the system is dissipated continuously; but,for small damping, the oscillations remain approximately periodic.

The dissipating forces are generally the frictional forces.

We can represent the damping graphically showing the decrease in amplitude with the passage of time.



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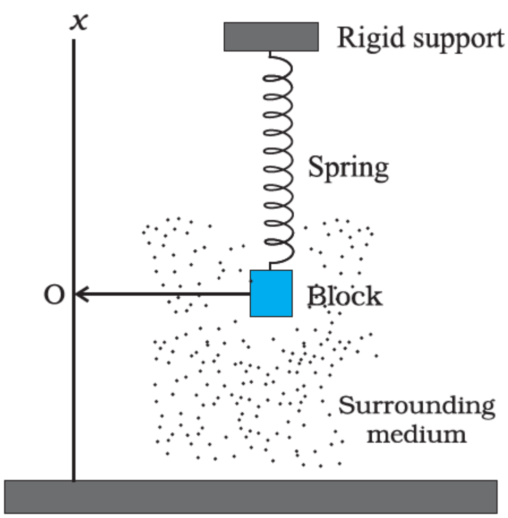
To understand the effect of such external forces on the motion of an oscillator, let us consider a system as shown in Fig



The viscous surrounding medium exerts a damping force on an oscillating spring, eventually bringing it to rest.

Here a block of mass *m* connected to an elastic spring of spring constant *k* oscillates vertically. If the block is pushed down a little and released, its angular frequency of oscillation is

$$\boldsymbol{\omega} = \sqrt{\frac{\mathbf{k}}{\mathbf{m}}}$$

However, in practice, the surrounding medium(air) will exert a damping force on the motion of the block and the mechanical energy of theblock-spring system will decrease. The energy loss will appear as heat of the surroundingmedium (and the block also)

The damping force depends on the nature ofthe surrounding medium. If the block isimmersed in a liquid, the magnitude of dampingwill be much greater and the dissipation ofenergy much faster. The damping force isgenerally proportional to velocity of the bob.
From Stokes' Law, and actsopposite to the direction of velocity.
If thedamping force is denoted by $\mathbf{F_d}$,

We have$\mathbf{F_d = -bv}$

where the positive constant **b**depends oncharacteristics of the medium (viscosity, temperature forexample) and the size and shape of the block,etc.

This is valid for only small velocities.

When the **mass *m***is attached to the springand released, the spring will elongate a little and the mass will settle at some height. This position,shown by O is **the equilibriumposition of the mass.**

If the mass is pulled downor pushed up a little, the **restoring force** on theblock due to the spring is

$\mathbf{F}_s = -k\mathbf{x}$,

where **x** isthe displacementof the mass from itsequilibrium position.

Thus, the **total force actingon the mass at any time *t***, *is* $\mathbf{F} = -k\mathbf{x} - b\mathbf{v}$.

If **a**(t) is the acceleration of mass at time t, then by Newton's Law of Motion applied along the direction of motion,

We have

$ma(t) = -k\, x(t) - b\, v(t)$

the new angular frequency will be

$$\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$

the mechanical energy of the undamped oscillator is

$$\frac{1}{2}kA^2$$

For a damped oscillator, the amplitude is not constant but depends on time. For small damping, we may use the same expression but regard the amplitude as

$$E(t) = \frac{1}{2}kA^2 e^{-bt/m}$$

shows that the total energy of the system decreases exponentially with time

6. FORCED VIBRATIONS

Whena body is subjected to an external periodic force (or a force whose magnitude and direction change periodically with time is called a 'periodic' force.) whose frequency is different from the natural frequency of the body, then in the beginning the body tends to vibrate with its natural frequency while the external periodic force tries to impose its own frequency upon the body.

Hence, there is a sort of tussle between the body and the external force due to which the amplitude of vibrations of the body undergoes periodic increase and decrease.

Theseirregular oscillations of the body, however, die out in a short time and finally the body vibrates with the frequency of the external periodic force with constant amplitude.

These vibrations are called 'forced vibrations'.

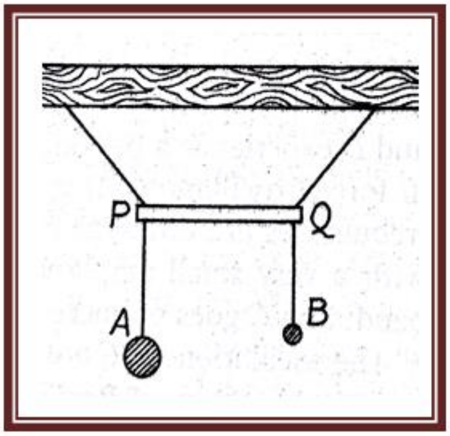
These are called 'forced' because **the body is forced to vibrate with the frequency of the external force, whatever be its natural frequency.**

Thus,

When a body is acted by an external periodic force, vibrates with the frequency of the force, then the vibration of the body are called 'forced vibrations'.

EXAMPLES:

(i) Two pendulums A and B of different lengths are suspended from the ends of a rod PQ as shown in fig. The natural frequencies of these pendulums are different. When the pendulum A is displaced and left free, it oscillates with its natural frequency. These oscillations are communicated to the pendulum B through the rod PQ. Thus, 'periodic' forces of frequency equal to the frequency of pendulum A acts upon the pendulum B. Therefore, the pendulum B is set in oscillation with the frequency of A. These oscillations of B are the forced oscillation. The amplitude of these oscillations is smaller than that of A.



(ii) When the stem of a vibrating tuning fork is held in hand, only a feeble sound is heard. If, however, the stem is made to stand on a table, the sound becomes intense. The reason is that on placing the stem on the table, the vibrations of the tuning fork are communicated to the babble which is set in forced vibrations. Because the surface area of the table is quite large, vibration of the table send out sound waves in a large volume of air.

Hence, the sound becomes intense. Since, now the tuning fork is giving intense sound, therefore its vibrational energy is lost rapidly and so its sound dies out rapidly.

(iii) All stringed musical instruments (as sonometer, piano, violin. sitar, etc.) carry a hollow box which is called the 'sound board'. It is helpful in increasing the intensity of notes. When a note of any frequency is produced in a string of the instrument, the vibrations of the string reach the hollow box through the bridge fixed below the string. Hence, forced vibrations are produced in the air inside the box and the intensity of sound increases.

https://www.flickr.com/photos/aplumb/5885565

https://www.maxpixel.net/Instrument-Musician-Guitar-Music-Street-Musician-2846049

https://commons.wikimedia.org/wiki/File:Tabla_-_Kolkata_2004-09-17_02315.JPG

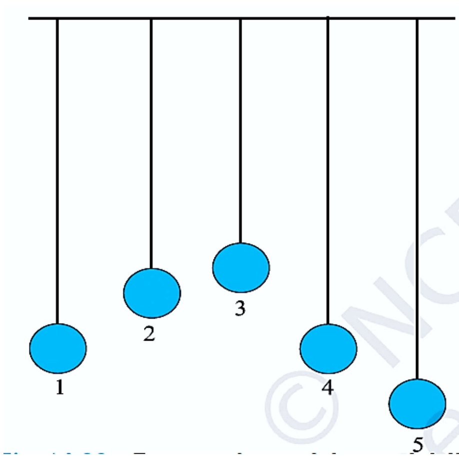
7. RESONANCE:

You must have experienced in a swing that when the timing of your push exactly matches with the time period of the swing, your swing gets the maximum amplitude. This amplitude is large,

If, the frequency of the external force is equal to the natural frequency of the body (or its integral multiple), then the amplitude of the forced vibrations (or oscillations) of the body becomes quite large.

This phenomenon is called 'resonance'.

Thus, resonance is a particular case of forced vibrations (or oscillations).



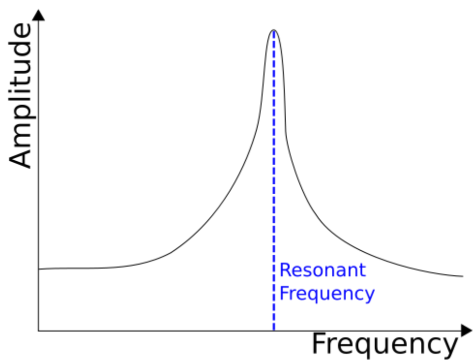
In Fig., five simple pendulums 1.2.3.4 and 5 are suspended from a thin cord. The lengths of the pendulums 1 and 4 are equal and so their frequencies are also equal.

The length of 4 is slightly greater and that of 2,3 is slightly smaller than 1 and 5

When **pendulum 1** is set into oscillations, the pendulums **2,3,4, and 5**experiences a periodic force of frequency equal to that of 1, and are set in forced oscillations.

It is seen that the **pendulums 2,3 and 5 (whose natural frequencies are different from the frequency of 1)** execute forced oscillations with **small amplitude,** but **the amplitude of forced oscillations of the pendulum 4 goes on increasing slowly and becomes equal to the amplitude of 1.**

These oscillations are resonant oscillations.



https://commons.wikimedia.org/wiki/File:Resonant_frequency_amplitude.svg

Graph shows maximum amplitude when the frequency of the driver system is equal to the natural frequency of the driven system frequency

Explanation of Resonance:

So there is a driver and a driven system
Both will have some natural frequency

When the **frequency of the external force(driver system)** is equal to the **natural frequency of the body (driver system)**then at each step the **force is in phase** with the **oscillating body.**

Hence, successive impulses given by the periodic force to the body are added up and increase the amplitude of oscillation continuously. But, with increasing amplitude the air resistance and internal friction also increase so that the loss of energy from the body also increases.

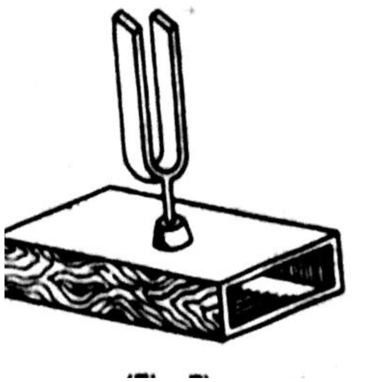
Finally, a stage is reached when the energy supplied by the external force becomes equal to the energy lost by the body. This stage of equilibrium is reached a little before the amplitude becomes very large. If there were no loss of energy, the amplitude would have become infinite.

We have so far considered oscillating systems which have just one natural frequency. In general, a system may have several natural frequencies. We have many examples of such systems vibrating strings, air columns, etc.

Any mechanical structure, like a building, a bridge, or an aircraft may have several possible natural frequencies. An external periodic force or disturbance will set the system in forced oscillation. If, accidentally, the forced frequency happens to be close to one of the natural frequencies of the system, the amplitude of oscillation will shoot up(resonance), resulting in possible damage.

THIS IS WHY

- **Soldiers passing over a suspension bridge always break steps because if the frequency of their march happens to coincide with the natural frequency of the bridge, the bridge may be set into violent oscillations and collapse**
- **If the frequency of revolution of the wheels of a train passing over a bridge coincides with the natural frequency of the bridge, then due to resonance, the bridge may be set into large-amplitude oscillations and there is a chance of its collapsing.**
- **For the same reason, an earthquake will not cause uniform damage to all building in an affected area, even if they are built with the same strength and materials. The natural frequencies of a building depend on its height, and other size parameters, and the nature of building materials. The one with its naturalfrequency close to the frequency of seismic wave in likely to be damaged more.**
- **Glass window panes vibrate or may even break when an aeroplane passes over the building**
- **Resonance Box:Generally the sound of a tuning fork, in vibrating string, wires is very soft. But, if we place a hollow box of dimensions such that the air inside the box has a natural frequency equal to that of vibrating system, an intense note is heard. This is because the air inside the box is set into resonant vibrations. Such a box is called ‘resonance box**



- **When two strings of the same natural frequency are stretched upon the same board and one of them is set into vibration, then the other also begins to vibrate.**
  The phenomenon has been used in various stringed musical instruments such as sitar, esraj, etc. In these instruments, along with the main wires, certain side wires are stretched.
  These wires are tuned for various frequencies. When any main wire is plucked, then a side wire of the same frequency becomes resonant. Hence, the intensity of the note is increased.

- **If we place an empty glass to our ear, a humming sound is heard. The reason is that in the surroundings various types of vibrations are always present in the atmosphere. Those vibrations whose frequencies coincide with the frequency of air in the glass makes the air resonate.**
- **You may cup you palm and hold it next to your ear and hear the humming sound .**

https://www.nicepng.com/png/detail/405-4052059_listeners-png.png

INTERESTING TO KNOW

The familiar *sound of the sea* that is heard when a seashell is placed up to your ear is also explained by resonance.

https://images-na.ssl-images-amazon.com/images/I/61LJJ325rXL._SL1418_.jpg

Even in an apparently quiet room, there are sound waves with a range of frequencies. These sounds are mostly inaudible due to their low intensity. This so-called background noise fills the seashell, causing vibrations within the seashell. But the seashell has a set of natural frequencies at which it will vibrate. If one of the frequencies in the room forces air within the seashell to vibrate at its natural frequency, a resonance situation is created.
The result of resonance is a vibration of large amplitude that is, a loud sound. In fact, the sound is loud enough to hear.

So next time you hear the *sound of the sea* in a seashell, remember that all that you are hearing is the amplification of one of the many background frequencies in the room.

ONE CRAZY INCIDENT

The Tacoma Narrows Bridge in Washington state, was with 1.9 km length, one of the largest suspended bridges built at that time.

The bridge connecting the Tacoma Narrows channel collapsed in a dramatic way on **Thursday November 7, 1940.**

See a video on forced oscillations and resonance

https://www.youtube.com/watch?v=mXTSnZgrfxM

Winds of 65-75 km/h produced an oscillation which eventually broke the construction.

The bridge began first to vibrate the torsionally, giving it a twisting motion.

Later, the vibrations entered a natural resonance frequency of the bridge which started to increase their amplitude

A car which had been left on the bridge could not be saved.

Unfortunately, it had a dog who (so goes the story) was so frightened that he would bite whoever would try to rescue him.

8. SHARP RESONANCE AND FLAT RESONANCE: EFFECT OF DAMPING

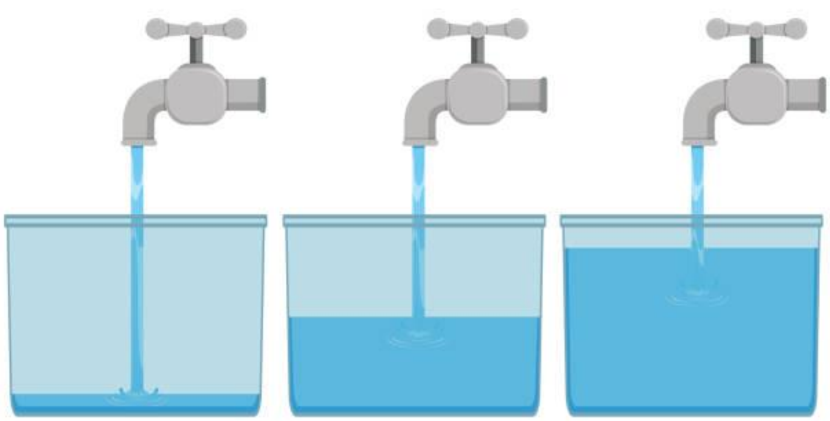
In the resonant vibrations of a body, the frequency of the applied periodic force is equal to the natural frequency of vibration of the body. If, on making the frequency of the external force slightly smaller or greater than the natural frequency of the body, the amplitude of vibrations falls sharply, then the resonance is said to be **‘sharp’.** If, on the other hand the amplitude decreases very slightly, then the resonance is said to be **‘flat’.**

When a body is in resonant vibration, then the sharpness or the flatness of resonance depends upon the ‘damping’ present in the body. Smaller the damping, sharper is the resonance.

9. RESONANCE TUBE

When an air column is set in to vibration it has a natural frequency dependent on the length of the column. You could produce a shrill sound by blowing into awhistle, a key with a long hole, or a narrow tube .the frequency of sound heard is distinctly different, the same sound can be produced by any other person blowing. The dissipation of energy increases the moment the air column is wide.

https://www.flickr.com/photos/64884898@N04/5942337785



https://www.istockphoto.com/in/vector/cleaning-bucket-icon-flat-graphic-design-gm509438406-85787021

This is a common experience when you can hear the frequency of the sound from the water filling up a bucket. The changing sound makes you realise when the bucket is about to be filled.

These are called resonance columns, as they can have variable lengths; the natural frequency of vibration of air in the column depends upon the length of the column, if the driver frequency matches the natural frequency of the air column,condition for resonance occurs and a loud sound is heard.

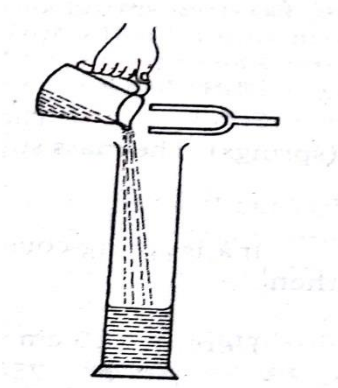
THINK ABOUT THIS

- **What is the driver system in a bucket?**
- **Which is the driven system in the bucket?**

- **What is the driver system in a flute?**
- **Which is the driven system in the flute?**

EXAMPLE

A tuning fork of frequency 480Hz is held at the mouth of a tall glass cylinder. Water is slowly poured into the cylinder



a) Identify the driver system
b) What is the frequency of the driver system?
c) Which is the driven system?
d) When will the condition for resonance satisfied?
e) What should be the natural frequency of the driven system?
f) Why does the natural frequency of air column change while that for tuning fork remains the same?

SOLUTION

a) the tuning fork

b) 480Hz
c) Air column
d) When the natural frequency of the air column is the same as the natural frequency of the tuning fork
e) 480 Hz
f) The length of the air column changes as the water fills in the cykubder.

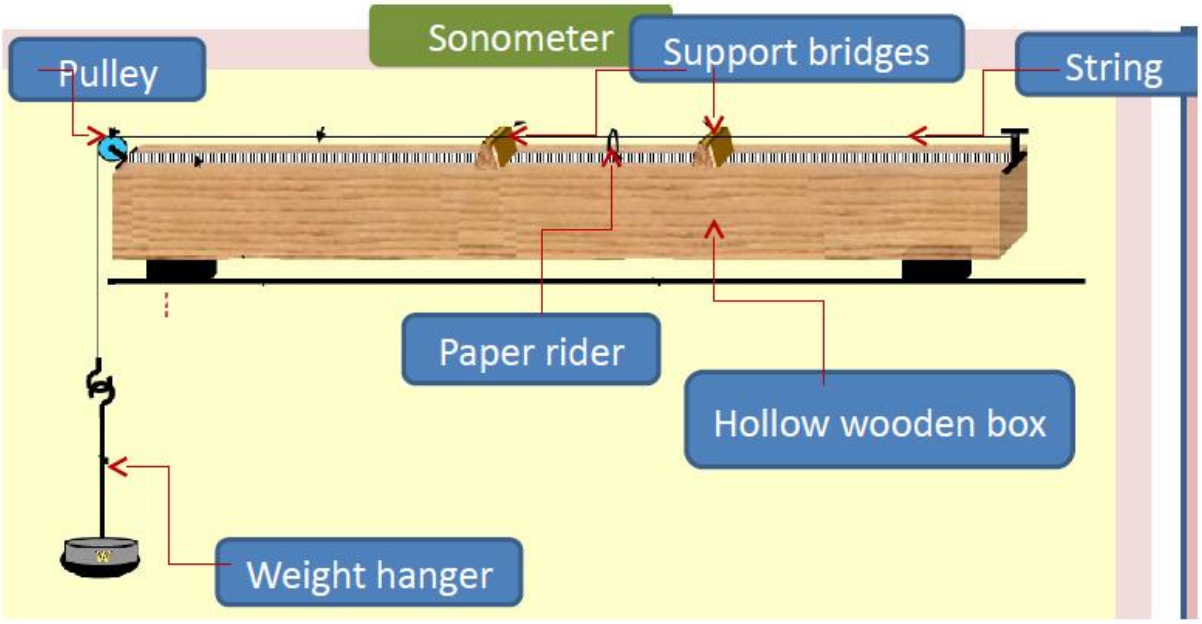
RESONANCE TUBE APPARATUS IN THE LABORATORY

The tube is mounted on its own support stand and connected with surgical tubing to its aluminum water reservoir. The reservoir is easily moved up and down with the knurled adjustment screw built into the support clamp.

It is used to measure the length of aircolumn where resonance is heard using a tuning fork of known frequency. The apparatus is used to determine velocity of sound at room temperature.

10. SONOMETER:

To explain the properties of sound using vibrating strings we use sonometer found in every laboratory.



Source: httpss://www.nextgurukul.in/wiki/

The factors on which the frequency of a stretched string depends are

- **Length of the string**
- **Tension applied to the string**
- **Mass per unit length of the string.**

The above diagram is an experiment to show how the frequency depends on the length.

First stretch a steel string over two movable bridges on a sonometer as shown and attach a constant weight to one end of the string.

Now strike a tuning fork of known frequency and stand it on one of the bridges. Keep moving the other bridge until resonance occurs.

Now resonance is detected by placing a small piece of paper on the string near the middle.

When resonance occurs, the amplitude of the vibrating wire increases so much that the piece of paper (called the reader) is thrown off. Measure the length, *l*, of the string and note the frequency, *f*, of the fork.

Now repeat with the forks of different frequencies keeping the tension constant. Now tabulate each value of length *l*, Calculate 1/*l*.

The graph between frequency and $\frac{1}{l}$ shows that the frequency of a vibrating wire depends directly of $\frac{1}{l}$

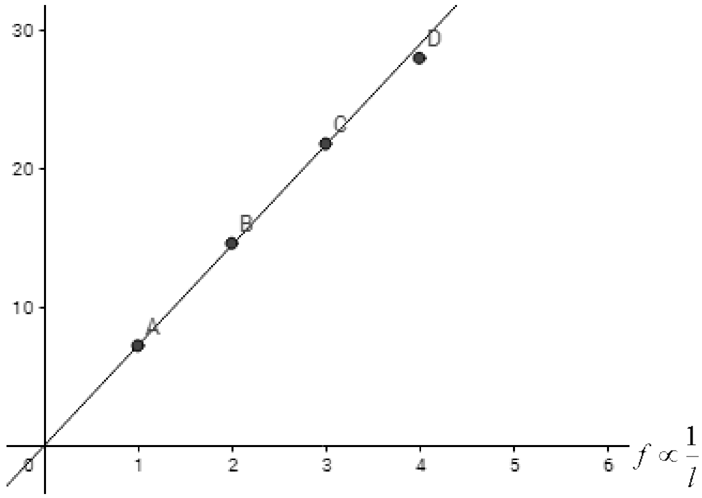


Fig: 8.6.2

https://www.geogebra.org/m/qYX5eakP

The apparatus used in the laboratory for many interesting experiments

Determination of Frequency: In the laboratory, in determining the frequency of a tuning fork by sonometer, we make use the principle of resonance. The fork is struck and placed vertically on a bridge on the sonometer. The wire between the two bridges is set in forced vibrations. Now, the other bridge on the sonometer is displaced to vary the vibrating length of the sonometer wire so that the natural frequency of the wire varies. At one particular length, the amplitude of vibrations becomes very large. This happens when the natural frequency of the wire becomes equal to the frequency of the tuning fork.

11. APPLICATIONS OF RESONANCE AROUND US

Almost every field of science and technology and wide spectrum of our daily life is using the applications based on the phenomenon of resonance; some of them are listed below.

- Musical instruments
- MRI scanners use nuclear magnetic resonance
- Radios and TVs have to be tuned to resonant frequencies to pick up stations.
- In microwave ovens the microwaves resonates with the natural frequencies of water and fat molecules.

- In the construction of bridges(the bridges have a natural frequency and hence soldiers break their rhythmic march to avoid resonance which could break the bridge),
- In the laboratory the phenomena of resonance is used to measure natural frequencies.

NMR spectroscopy uses resonance to determine the properties of various materials, etc.

12. SUMMARY:

- The motions which repeat themselves are called periodic motions.
- The period T is the time required for one complete oscillation, or cycle. It is related to the frequency ν by, $\nu = 1/T$
- The frequency ν of periodic or oscillatory motion is the number of oscillations per unit time. In the SI system, it is measured in hertz : 1 hertz = 1 Hz = 1 oscillation per second = $1s^{-1}$
- In simple harmonic motion (SHM), the displacement x (t) of a particle from its equilibrium position is given by, $x(t) = Acos(\omega t + \varphi)$ (displacement), in which A is the amplitude of the displacement, the quantity $(\omega t + \varphi)$ is the phase of the motion, and φ is the phase constant.
- The angular frequency ω is related to the period and frequency of the motion by, $2\pi/$ T or ω= 2 πν (angular frequency).
- Simple harmonic motion is the projection of uniform circular motion on the diameter of the reference circle.
- The particle velocity and acceleration during SHM as functions of time are given by, $v(t) = -\omega Asin(\omega t + \varphi)$ (velocity), $a(t) =- \omega^2 Acos(\omega t + \varphi) =- \omega^2 x(t)$ (acceleration), Thus we see that both velocity and acceleration of a body executing simple harmonic motion are periodic functions, having the velocity amplitude $v_m = \omega\ A$ and acceleration amplitude $a_m\ = \omega^2 A,$ respectively.
- The mechanical energy in a real oscillating system decreases during oscillations because external forces, such as drag, impede the oscillations and transfer mechanical energy to thermal energy. The oscillator motion is then said to be damped.
- If an external force with angular frequency ω_d acts on an oscillating system with natural angular frequency ω, the system oscillates with angular frequency, ω_d. The amplitude of oscillations is the greatest when $\omega_d\ =\ \omega a$ condition called resonance.

- If the damping force is given by $F_d = -bv$, where v is the velocity of the oscillator and b is a damping constant, then the displacement of the oscillator is given by, $x(t) = Ae^{-bt/2m}cos(\omega' t + \varphi)$where ω′ is the angular frequency of the damped oscillator.

- In forced oscillations, the steady state motion of the particle (after the force oscillations die out) is simple harmonic motion whose frequency is the frequency of the driving frequencyω_d, not the natural frequency ω of the particle.

- In the ideal case of zero damping, the amplitude of simple harmonic motion at resonance is infinite. All real systems have some damping, however, small.

- Under forced oscillation, the phase of harmonic motion of the particle differs from the phase of the driving force.