1. Details of Module and its structure

Subject Name	Physics
Course Name	Physics 02 (Physics Part 2 ,Class XI)
Module Name/Title	Unit 10, Module 11, Properties of Waves Chapter 15, Waves
Module Id	keph_201503_eContent
Pre-requisites	Simple harmonic motion, wave motion, longitudinal and transverse waves, wave equation and propagation of waves, speed of waves in solids, liquids and gases, Superposition of waves
Objectives	After going through this module, the learners will be able to: • **Understand** Properties of waves • **Know** reflection of waves and the difference between reflection of mechanical waves from rigid and non-rigid boundaries • **Recognize** that a travelling wave undergoes a phase change of π on reflection from a rigid boundary • **Graphically** represent reflection of waves • **Understand** formation of stationary waves • **Differentiate** between reflection and refraction of waves • **Recognise** interference and diffraction of waves
Keywords	Reflection of wave, rigid , reflection of wave from a non-rigid boundary, refraction of wave, diffraction of wave, interference of waves, formation of stationary waves

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

	• To study variation of time period of a simple pendulum of a given length by taking bobs of same size but different masses and interpret the result • Using a simple pendulum plot its L-T^2graph and use it to calculate the acceleration due to gravity at a particular place
Module 8	• Free vibration natural frequency • Forced vibration • Resonance • To show resonance using a sonometer • To show resonance of sound in air at room temperature using a resonance tube apparatus • Examples of resonance around us
Module 9	• Energy of oscillating source, vibrating source • Propagation of energy • Waves and wave motion • Mechanical and electromagnetic waves • Transverse and longitudinal waves • Speed of waves
Module 10	• Displacement relation for a progressive wave • Wave equation • Superposition of waves
Module 11	• Properties of waves • Reflection • Reflection of mechanical wave at i)rigid and ii) non rigid boundary • Refraction of waves • Diffraction
Module 12	• Special cases of superposition of waves • Standing waves • Nodes and antinodes • Standing waves in strings • Fundamental and overtones • Relation between fundamental mode and overtone frequencies, harmonics • To study the relation between frequency and length of a

	given wire under constant tension using sonometer • To study the relation between the length of a given wire and tension for constant frequency using a sonometer
Module13	• Standing waves in pipes closed at one end, • Standing waves in pipes open at both ends • Fundamental and overtones • Relation between fundamental mode and overtone frequencies • Harmonics
Module 14	• Beats • Beat frequency • Frequency of beat • Application of beats
Module 15	• Doppler effect • Application of Doppler effect

MODULE 11

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
- Non mechanical displacement periodically changing electric, magnetic, pressure of gases, currents, voltages are non-mechanical oscillations. They are represented by sin and cosine functions like mechanical displacements

  For a vibration or oscillation, the displacement 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

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

- 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 am equilibrium (mean) position, so that the maximum displacement on one side of this position is equal to the maximum displacement on the other side. The time interval of each complete vibration is the same.
- **Harmonic oscillator:** A *harmonic oscillator* is a *physical* system that, when displaced from equilibrium, experiences a restoring force proportional to the displacement.
- **Mechanical energy:** is the sum of potential **energy** and kinetic **energy**. It is the **energy** associated with the motion and position of an object.
- **Restoring force:** is a *force* exerted on a body or a system that tends to move it towards an equilibrium state.
- **Conservative force:** is a *force* with the property that the total work done in moving a particle between two points is independent of the taken path. When an object moves from one location to another, the *force* changes the potential energy of the object by an amount that does not depend on the path taken.
- **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'

  - **Displacement Equation for a SHM:**

$$\boldsymbol{y = A\, sin\, \omega t}$$

- **Amplitude**: The maximum value of **sin ωt** is 1. The maximum value of the displacement y will be "A". This maximum displacement (for a SHM) is called the 'amplitude' of motion. It is equal to the radius of the reference circle.

- **Periodic time:** The time taken to complete one vibration; it also equals the time to go once around a circle of reference ($T = 2\pi/\omega$).
- **Frequency:** The number of oscillations, completed by the oscillating particle in one second, is called as its 'frequency' (f).

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

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

  $\mathbf{y = a \sin(\omega t + \phi)}$, ϕ is called the 'initial phase'. We usually take $\phi = 0$, when we are talking about the SHM of a single particle.

- **Velocity in SHM**: The velocity (v) of the particle P, executing a SHM, can be expressed as a function of its displacement (y) from its mean position:

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

- **Acceleration in SHM:** For the particle executing a SHM, the acceleration (α) is directly proportional to the displacement (y) from the mean position and is always directed opposite to the instantaneous displacement. Hence, $\alpha = -\omega^2 y$ and

$$\alpha_{max} = -\omega^2 a$$

- **Energy:** In equilibrium position $y = 0$, we have

Potential energy of the body, $U = 0(zero)$

And kinetic energy of the body, $K = \frac{1}{2} m\,\omega^2\, a^2 = E_{max}$

In maximum displace position ($y = a$), we have

Potential energy of the body, $U = \frac{1}{2} m\,\omega^2\, a^2 = E_{max}$

And kinetic energy of the body, $K = O(zero)$

- Wave motion: method of energy transfer from a vibrating source to any observer.
- Mechanical wave energy transfer by vibration of material particles in response to a vibrating source examples water waves, sound waves , waves in strings
- The speed of wave in medium depends upon elasticity and density

- Longitudinal mechanical wave a wave in which the particles of the medium vibrate along the direction of propagation of the wave
- Transverse mechanical wave a wave in which the particles of the medium vibrate perpendicular to the direction of propagation of the wave
- **A progressive wave:** The propagation of a wave in a medium means the particles of the medium perform simple harmonic motion without moving from their positions, then the wave is called a simple harmonic **progressive wave**

- **Displacement relation for a Progressive wave:** The displacement of the particle at an instant t is given by,

  $$y = a \sin\ (\omega\, t - \phi\ ) \text{ OR } y\ = a\ \sin\ (\omega\, t - k\, x\ )$$

  If ϕ be the phase difference between the above wave propagating along the +X direction and another wave, then the equation of that wave will be

  $$y = a \sin \left\{2\pi \left(\frac{t}{T} - \frac{x}{\lambda}\right) + \phi\right\}$$

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

  The displacement could also be expressed in terms of the cosine function without affecting any of the subsequent relation.

- **Particle Velocity:** The equation of a plane progressive wave propagating in the positive direction of X-axis is given by

  $$v = \frac{dy}{dt} = \omega\, a\, cos\ (\omega\, t - k\, x)$$

  The maximum particle velocity is given by,

  $v_{max} = \omega\, a$, this is known as velocity amplitude of particle.

- **Particle Acceleration:** The instantaneous acceleration f of a particle is

  $$f = \frac{du}{dt} = \omega^2\, a \sin(\omega\, t - k\, x) = -\omega^2\, y$$

  The maximum value of the particle displacement y is a. Therefore, acceleration amplitude is $f_{max} = -\omega^2\, a$

- **Principle of Superposition:** If y_1, y_2 *and* y_3 and so on are the displacements at a particular time at a particular position, due to the individual waves, the resultant displacement will be

  $y = y_1 + y_2 + y_3$ ….……….

When two or more waves traverse the same medium, the displacement of any element of the medium is the algebraic sum of the instantaneous displacements due to each wave. This is known as the *principle of superposition* of waves

4. INTRODUCTION

We are familiar that in wave-motion, although the particles, the medium do not leave their positions. But energy propagates from one part of the medium to the other.

Wave speed may exceeds particle speed

A wave in a medium can be much more rapid than the motion of individual particles of the medium, and the energy can be transported by wave motion faster than might be possible through net transport of matter.

Another interesting feature is that all kinds of waves i.e. transverse, longitudinal and surface can be seen to coexist, like in an earthquake. The longitudinal waves are fastest and surface waves are slowest.

In a medium, two or more waves can propagate simultaneously without affecting each other's motion; however at the region of overlap the wave displacement combine.

What happens to waves when they encounter an obstacle or a boundary?

Waves reaching the interface of two media are partly reflected and partly refracted.

We will now understand the special features of reflection refraction and subsequent effects.

This phenomenon of superposition or of interference and diffraction do occur in waves. Similarly, the phenomenon of polarization does occur in transverse waves.

PROPERTIES OF WAVES

We are well known that reflection of light takes from the surface of plane mirror or any polished medium even if the size of the surface is very small. But in case of mechanical such as sound waves, the wavelength is very large as compared to light wave, so any hard and plane wooden board can serve as a reflector of mechanical waves.

We can demonstrate the reflection of sound or mechanical waves from different surfaces or medium as well.

Sound waves are very similar in behavior to light wave as far as the phenomenon of refraction, diffraction, transmission and interference. These wave properties will be discussed here one by one.

For simplicity we will first consider the properties for sound waves and extend the ideas to other waves.

5. REFLECTION OF WAVES:

The reflection of sound follows the laws of reflection for light. You had even confirmed it in the science class.

Salient features

Laws of reflection, as you may recall are

- The incident ray, the reflected ray and the normal at the point of incidence lie in the same plane
- The angle of reflection is equal to the angle of incidence

To these we may now add more

- The amplitude of the reflected ray is less than the incident wave as some loss of energy either due to absorption or transmission will be there.
- The wave speed of the reflected wave is the same as incident wave speed in a homogeneous medium.
- The frequency and wavelength of the reflected wave is also the same as that for incident wave.
- Something **interesting happens to phase** at the boundary of reflection.

  A boundary may be rigid like a stone wall, a wooden door, a cement floor or it may be non-rigid like an open window, an open door an open tube.

  Now **how does an open window form a boundary**?

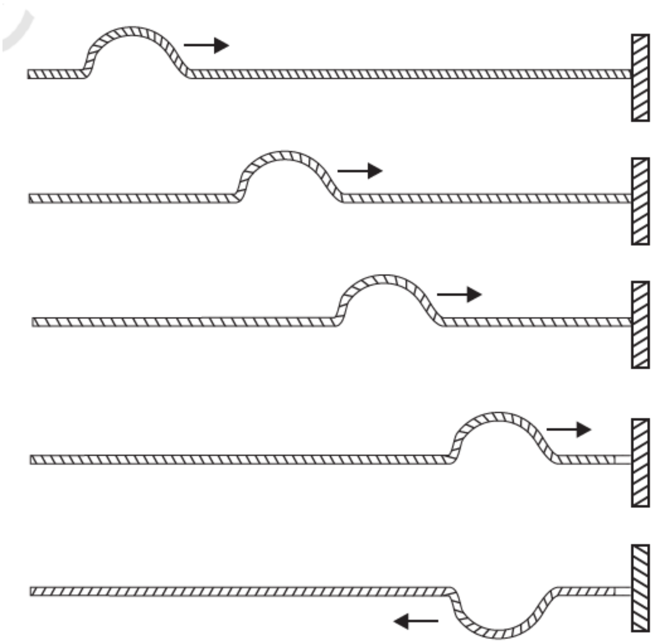
  Imagine a room with an open window. The density, temperature and atmospheric condition of air inside the room will be different. Hence the wave reaching the open window would reflect and refract much like it would do at a rigid boundary.

a) Reflection of a progressive wave from a rigid boundary

If the boundary is rigid, the pulse or wave gets reflected. The phenomenon of echo is an example of reflection by a rigid boundary.

If the boundary is **not completely rigid** or is **an interface between two different elastic media**, the situation is somewhat complicated.

A part of the incident wave is reflected and a part is transmitted into the second medium. If a wave is incident obliquely on the boundary between two different media the transmitted wave is called the **refracted wave**. The incident and refracted waves obey Snell's law of refraction, and the incident and reflected waves obey the usual laws of reflection.



The figure shows a pulse travelling along a stretched string and being reflected by the boundary.

Assuming there is no absorption of energy by the boundary, the reflected wave has the same shape as the **incident pulse but it suffers a phase change of π or 180^0 on reflection**.

This is because the boundary is rigid and the disturbance must have zero displacement at all times at the boundary.

By the principle of superposition, this is possible only if the reflected and incident waves differ by a phase of π, so that the resultant displacement is zero.

This reasoning is based on boundary condition on a rigid wall.

We can arrive at the same conclusion dynamically also.

- As the pulse arrives at the wall, it exerts a force on the wall.
- By Newton's Third Law, the wall exerts an equal and opposite force on the string generating a reflected pulse that differs by a phase of π.

(b) Reflection of a progressive wave from a free Surface or non-rigid boundary

If on the other hand, the boundary point is not rigid but completely free to move (such as in the case of a string tied to a freely moving ring on a rod), the reflected pulse has the same phase and amplitude (assuming no energy dissipation) as the incident pulse. The net maximum displacement at the boundary is then twice the amplitude of each pulse.

When the pulse of the incident wave reaches the free end, then there is no change in its phase and the wave returns in the same way as it would have advanced in the absence of the reflected surface.

To summarize, a travelling wave or pulse suffers a phase change of π on reflection at a rigid boundary and no phase change on reflection at an open boundary.

Due to incident and reflected waves overlapping condition for superposition is satisfied. At any instant the displacement of medium particles is given by principle of superposition.

Predictable and supported by mathematics the resultant wave is special.

They are called stationary or standing waves

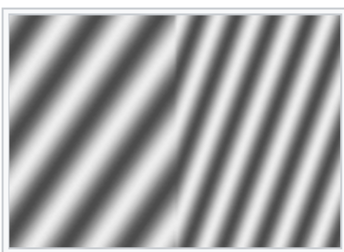
6. REFRACTION OF WAVES

This is the phenomenon of a wave changing its speed that is the wave velocity changes. This refraction occurs when a wave passes from one medium into another. Imagining a distinct boundary, a distinct surface between the medium and that the mediums are homogeneous. Heterogeneous medium will give refraction which will follow the rules of refraction but the refracted wave may not be so easy to predict. The amount by which a wave is refracted by a material is given by the refractive index of the material. The directions of incidence and refraction are related to the refractive indices of the two materials by **Snell's law**.

Refraction [edit]

Main article: Refraction

Refraction is the phenomenon of a wave changing its speed. Mathematically, this means that the size of the phase velocity changes. Typically, refraction occurs when a wave passes from one medium into another. The amount by which a wave is refracted by a material is given by the refractive index of the material. The directions of incidence and refraction are related to the refractive indices of the two materials by Snell's law.



Sinusoidal traveling plane wave entering a region of lower wave velocity at an angle, illustrating the decrease in wavelength and change of direction (refraction) that results.

Diffraction [edit]

Main article: Diffraction

Source: https://en.wikipedia.org/wiki/Wave#Refraction

Salient features

- **The velocity of wave changes as it goes from one homogeneous medium to another.**
- **The waves follow Snell's law for oblique incidence.**
- **The refractive index may be defined as** $_1\mu_2 = \frac{velocity\ of\ wave\ in\ medium 1}{velocity\ of\ wave\ in\ medium\ 2}$
- **The amplitude of refracted wave will be less as compared to incident wave as some energy may be lost in absorption and reflection**
- **The wavelength changes $v = f\lambda$**
- **The frequency of the wave does not change as it is the property of the source of energy.**
- **There is no change in phase, as it was in the case of reflection.**

7. SPECIAL CASES OF SUPERPOSITION OF WAVES

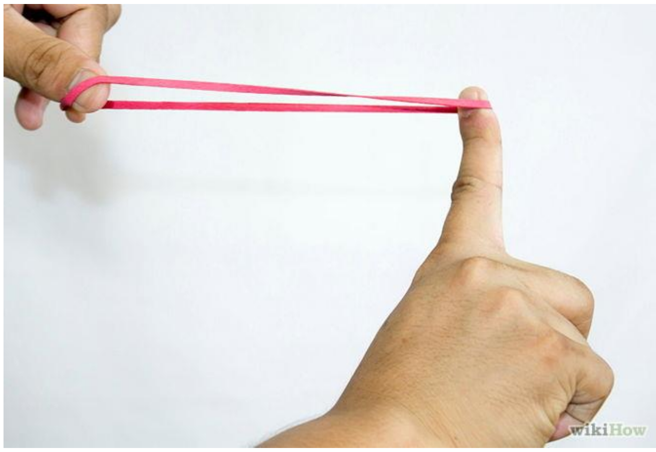
In a string, a wave going to the right will get reflected at one end, which in turn will travel and get reflected from the other end. This will go on until there is a steady wave pattern set up on the string. Such wave patterns are called standing waves or stationary waves.

a) STATIONARY (OR STANDING) WAVES

When two identical transverse or longitudinal, progressive waves propagate in a bounded medium with the same speed, but in opposite directions, then by their superposition, a new type of wave is produced which appears stationary in the medium. This wave is called the 'stationary (or standing) wave'.

For example,

A rubber band held at its ends is made to vibrate



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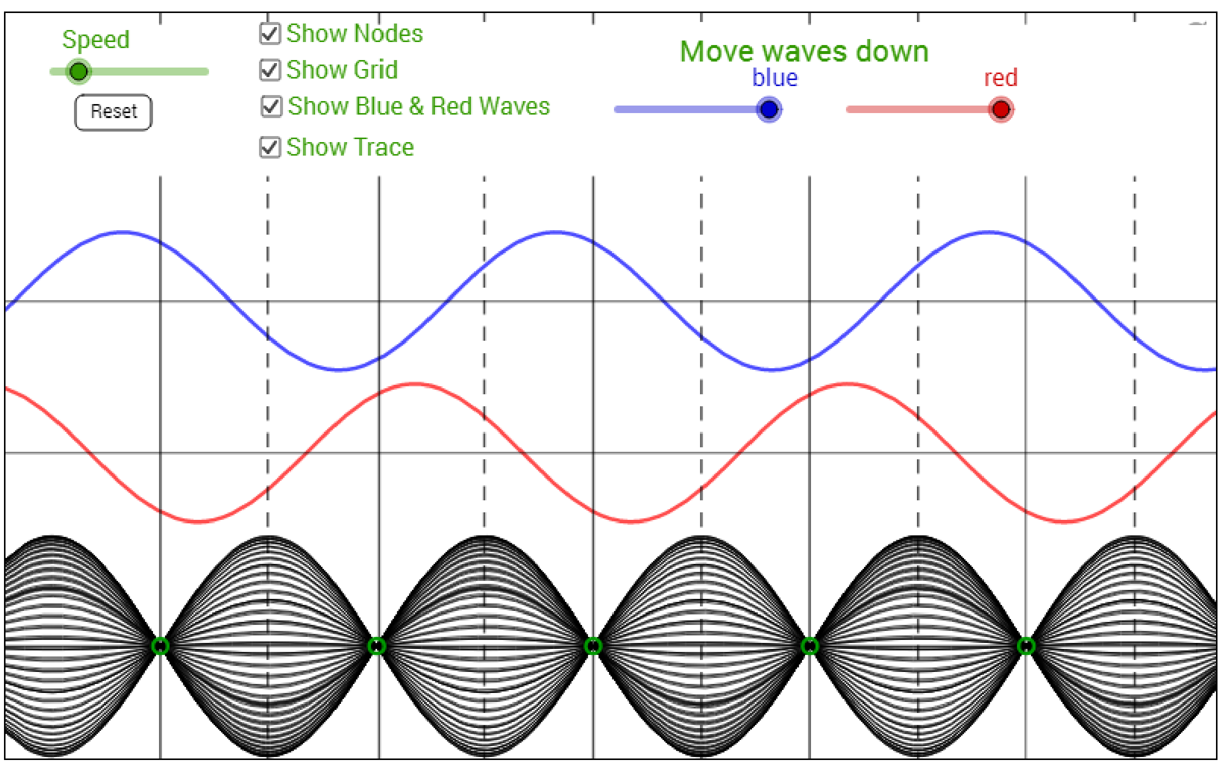
When a wave is sent along a string, it is reflected from the end of the string; then reflected and the incident waves superpose to form stationary waves in the string.

Transverse stationary waves are formed in the string of sitar, violin, guitar, etc. Similarly, a longitudinal wave sent in an air column of a pipe is reflected from the end of the pipe, and the reflected and incident waves superpose to form stationary waves in the air column. Longitudinal stationary waves are formed in the air-columns of flute, bigule, bina, whistle, etc.

Nodes and Antinodes: The characteristic of the stationary wave is that some particles of the medium remain permanently at rest, while some other particles undergo maximum displacement compared to others. The former are called the **"nodes"** and the latter the **"antinodes".**

Condition of Formation of Stationary Waves: For the formation of stationary waves, the medium should have a boundary. The wave propagating on such a medium will be reflected at the boundary and produce a wave of the same kind travelling in the opposite direction. The superposition of the two waves will give rise to a stationary wave. Hence, a "bounded" medium is an essential condition for the formation of stationary waves

For more understanding click here: https://www.geogebra.org/m/W8etDR28



Source: geogebra

When stationary waves are formed on a string, the string gets divided into loops. Each loop performs up and down motion, but the up and down motion of loops pattern in each, happens so rapidly that it appears as if the loops are stationary.

b) INTERFERENCE OF WAVES

Interference is a phenomenon in which two waves superimpose to form a resultant wave of greater or lower amplitude.

Conditions for interference

Two waves

- propagating in the same direction
- Having same wavelength
- Having same frequency

Result in redistribution of energy in space

Interference usually is an interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the almost same frequency. Interference effects can be observed with all types of waves, including light, radio, sound, and mechanical waves.

Source: https://en.wikipedia.org/wiki/Interference (wave propagation)

c) BEATS

The phenomenon of wavering of sound intensity when two waves of nearly equal frequencies and amplitudes travelling in the same direction are superimposed on each other is called beats

Beats is a special phenomenon used by musicians to tune their instruments.

It occurs when two waves travel through the same medium with slightly different frequencies, in the same direction –along same line simultaneously.

Conditions for Beats

Two sound waves

- propagating in the same direction
- Having same or nearly the same amplitude
- slightly different frequency are sounded together

Result in redistribution of energy in time

Beats are waxing and vanning of sound when two nearly same frequency sources are sounded together. It is not necessary that the source of the close frequency is same type. For example beats can be produced with waves from a tuning fork and table, sitar wire and guitar wire

8. DIFFRACTION

Diffraction refers to various phenomena that occur when a wave encounters an obstacle or a slit. It is defined as the **bending of waves around the corners of an obstacle or aperture into the region of geometrical shadow of the obstacle.**

Diffraction occurs with all waves, including sound waves, water waves, and electromagnetic waves such as visible light, X-rays and waves. Therefore, bend waves around obstacles and spread out past small openings.

It happens mostly with the waves having **almost same wave length as the diffraction objects**. For example, the closely spaced tracks on a CD or DVD act as a diffraction grating to form the familiar rainbow pattern seen when looking at a disk.

Source: https://en.wikipedia.org/wiki/Diffraction

9. POLARISATION

It is a property especially of transverse waves. The transverse vibrations of the wave can be restricted or polarised in a special way. Example: plane polarization –which means restricting the transverse vibration to a plane. We can also obtain circular polarised and elliptically polarised waves. This wave property is useful in transverse electromagnetic waves example light. Thus the wave property that specifies the geometrical orientation of the oscillations is called polarization

TRY THESE

i) Sound waves of wavelength λ travelling in a medium with a speed of v m/s enter into another medium where its speed is 2v m/s. Wavelength of sound waves in the second medium is

a) λ

b) $\frac{\lambda}{2}$

c) 2λ

d) 4λ

Answer: (c)

ii) Equation of a plane progressive wave is given by $y = 0.6 \sin 2\pi \left(t - \frac{x}{2}\right)$

On reflection from a denser medium its amplitude becomes 2/3 of the amplitude of the incident wave. The equation of the reflected wave is

(a) $y = 0.6 \sin 2\pi \left(t + \frac{x}{2}\right)$

(b) $y = -0.4 \sin 2\pi \left(t + \frac{x}{2}\right)$

(c) $y = 0.4 \sin 2\pi \left(t + \frac{x}{2}\right)$

(d) $y = -0.4 \sin 2\pi \left(t - \frac{x}{2}\right)$

Answer: (b)

10. SUMMARY

- Waves exhibit different properties
- **Superposition of waves**

  Principle of Superposition: If y_1, y_2 *and* y_3 and so on are the displacements at a particular time at a particular position, due to the individual waves, the resultant displacement will be

  $y = y_1 + y_2 + y_3$ ….……….

- Reflection waves reflect when they encounter boundaries. The boundary could be rigid or non-rigid. There is phase reversal when a wave is reflected from a rigid boundary. There is no phase change when a wave is reflected from a non-rigid boundary
- **Bounded medium:** A "bounded medium" is one which has definite boundaries and whose boundaries are separated from other media by distinct surfaces.
- **Refraction of waves:** This is the phenomenon of a wave changing its speed. That is the size of the phase velocity changes. The refraction occurs when a wave passes from one medium into another.
- **Interference of waves**: The Interference is a phenomenon in which two waves superimpose to form a resultant wave of varying or lower amplitude.
- **Diffraction:** Diffraction refers to various phenomena that occur when a wave encounters an obstacle or a slit. It is defined as the bending of light around the corners of an obstacle or aperture into the region of geometrical shadow of the obstacle. The size of the obstacle must be the same as the wavelength.

- **Stationary waves** a special case of superposition. a wave and its reflected wave superpose to localize the energy. Since the energy does not travel in the medium but remain in a region they are called stationary waves.

- **Node and Antinode:** When two waves add with opposite phase and cancel each other out. They form **nodes.** Nodes occur at intervals of half a wavelength ($\lambda/2$). Midway between each pair of nodes are locations where the amplitude is maximum. These are called the **antinodes.**