Unit
08

WAVES

Q.1 Define Wave. What are its type? Discuss.

Ans. Definition:

"Disturbance produced by the vibrating body which carries energy is known as wave".

Type: For producing waves vibrating body is required. The types of waves are:-

1. Mechanical waves.
2. Electromagnetic waves.
3. Particle waves.

Mechanical waves:

The waves, which require material medium for their propagation, are known as mechan waves.

(i) Sound waves
(ii) Waves produced in over stretched strings
(ii) Water waves

Electromagnetic waves:

The waves, which do not require any material medium for their propagation, are known electromagnetic waves.

1. Light waves
2. Heat waves
3. X-rays
4. Gamma rays

Particle waves:

"The waves associated with particles such as electrons protons and etc when they are mov with very high speed are known as particle waves or matter waves or de Broglie waves".

Progressive waves or travelling waves: **(Board 2008)**

A wave, which transfers energy by moving away from the source of disturbance, is cal progressive or traveling wave.

Example:

Drop pebble into water ripples are produced and spread out across the water. The ripples a example of progressive waves because they carry energy across the water surface.

Q.2 What are mechanical waves? What are their types? Differentiate between longitudi and transverse waves.

Ans. The waves which cannot travel without a medium are known as mechanical waves. Mechanical waves are classified as:

(1) Transverse waves.
(2) Longitudinal waves.

When waves travel through the medium then energy carried by the wave is transferred from particle to particle. During this course, the particles of the medium start vibrating about their mean position.

Transverse waves:

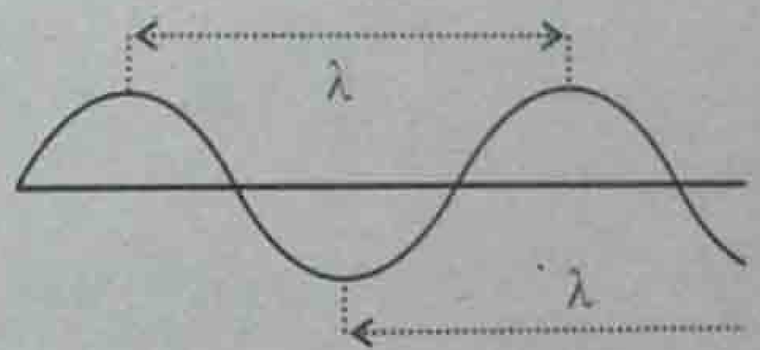
The waves in which particle of the medium are displaced in a direction perpendicular to the direction of propagation of waves are called transverse waves.

Crest:

The portion of the transverse waves above the mean level is known as crest.

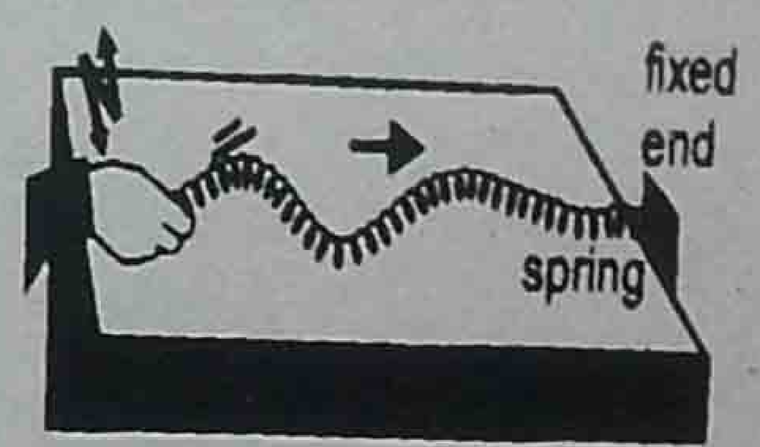
Trough:

The portion of transverse waves below the mean level is known as trough. The distance between the centers of two consecutive crests or troughs is known as wave length. It is denoted by (λ).



Example:

Suppose a long and loose (slinky spring) spring is lying on a smooth table whose one end is fixed. So that the spring does not sag under gravity. Now, if the free end of the spring is moved from side to side pulse of wave having pattern shown in the figure will be produced and it will move along the spring, other examples:- (i) Radio wave (ii) Light wave (iii) Microwave (iv) Water wave (v) Wave produced in stretched string.



Longitudinal waves:

Definition:

"The waves in which the particles of the medium are displaced in the direction parallel to the direction of propagation of waves are called longitudinal wave."

(1) Sound waves in air. (2) Waves produced in a spring.

Longitudinal waves travel in form of compression and rarefaction.

Compression:

The region of air, where the pressure is slightly greater than atmospheric pressure when sound waves travel through the air, is known as compression.

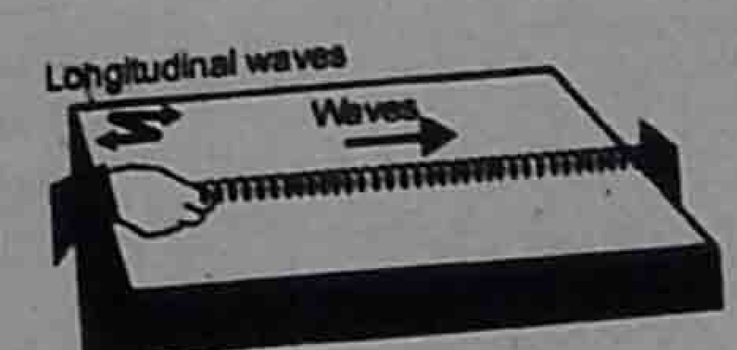
Rarefaction:

The region of air where the pressure is slightly less than the atmospheric pressure when sound waves propagate through it, is known as rarefaction.

⇒ The distance between two consecutive compressions or rarefactions is known as wavelength.

Examples:

Suppose a long and loose (slinky spring) spring is lying on a smooth table whose one end is fixed so that the spring does not sag under gravity. Now, if the free end of the spring is moved back and forth a pulse of wave having pattern shown in figure will be produced and it will move along the spring.



Frequency of the waves:

The number of waves passing through a reference point in a medium in one sec. is know frequency. If 'N" are the number of waves passing through a reference point in a medium in 't' then its frequency is written as

$$f = \frac{N}{t}$$

It is measured in Hz.

Speed of the waves:

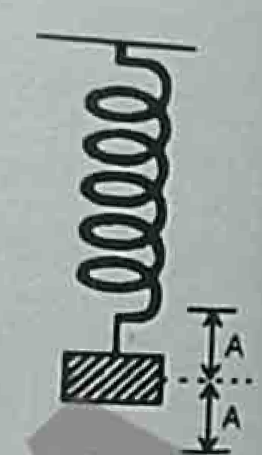
The distance covered by the disturbance produced by the vibrating body per second is know the speed of a wave. It is also called phase velocity.

$$v = \frac{s}{t}$$

Q.3 What are Periodic Waves? Establish relation between frequency (f), wavelength (λ) speed (v).

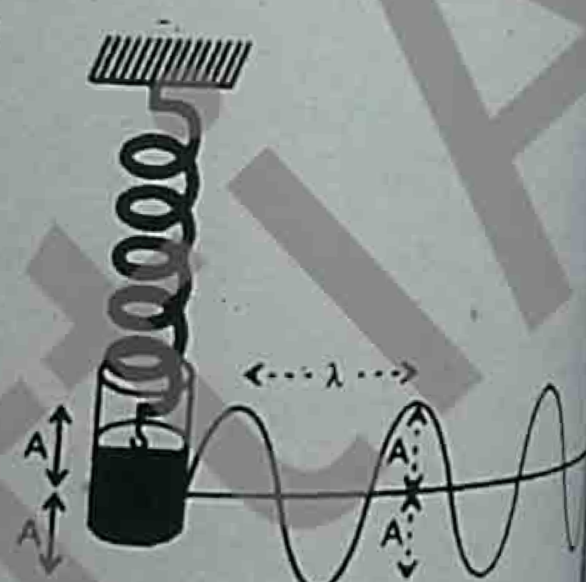
Ans. Periodic waves:

Consider an oscillating mass spring system as shown in figure. When we give a periodic motion to the free end of the spring then each particle in the spring will under go periodic motion and we have a periodic wave. Thus "Continuous and regular periodic disturbance produced in a medium by a source produces periodic wave in that medium".



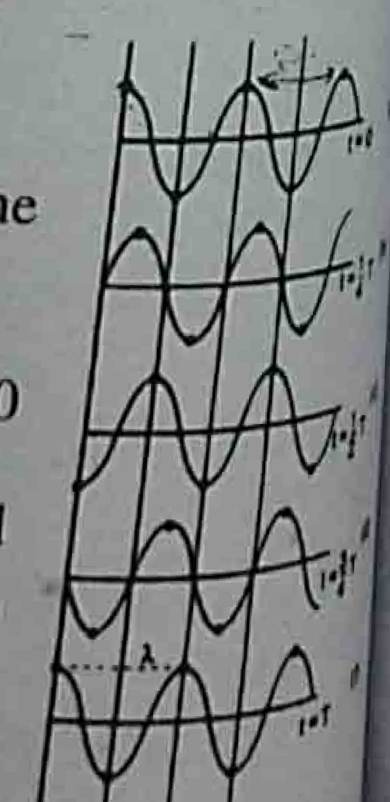
Transverse Periodic Wave:

Consider a vertically suspended mass spring system. A rope is fastened to the mass of the vibrator. As the mass spring system vibrates up and down we observe a transverse periodic wave traveling along the rope as shown in figure 1. Now source is moving up and down with amplitude 'A' and frequency 'f'. The each particle of the rope will execute S.H.M with the same amplitude and frequency. The wave traveling toward right in terms of crests and troughs replacing one another but the particles of the rope simply oscillate.



Relation between speed, wavelength and frequency

When wave progress then each particle of the medium oscillate with the period and frequency of source as shown in the figure these photographs are taken after every $\frac{1}{4}$ period. The crest started out from the extreme left at t=0 the time that this crest takes to move distance of one wave length 'λ' is equal to the time required for a point (particle) in the medium to go through one complete vibration thus the speed 'v' of the crest is given by



$$v = \frac{\text{Distance travelled}}{\text{time period}} = \frac{S}{t}$$

Distance S= λ = wave length

Time interval =t=T=time period

$$v = \frac{\lambda}{T} = f\lambda$$

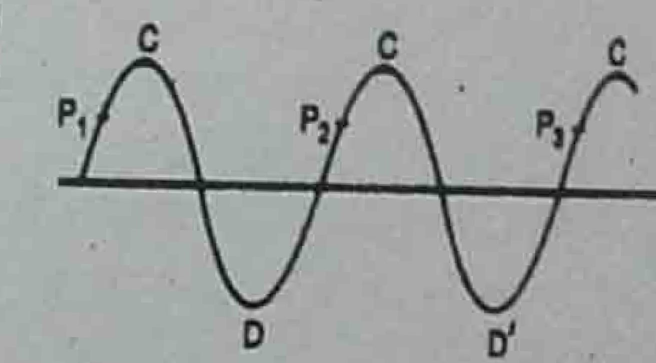
$$\boxed{v = f\lambda}$$

This is the general equation of all types of wave motion i.e. waves on spring or string, sound waves, water waves and radio wave. A transverse periodic wave is represented by sine curve.

Q.4 How a phase difference between the two points on a wave is related with distance between them? 11108004

Ans. Phase Relation between Two points on a wave:

The fig represents the snapshot of the wave profile produced by a source executing S.H.M. In fig point C and C′ are shown which are in same state of motion, as the wave passes. At these points the medium particles have identical displacement and velocity. Therefore we can say that points C and C′ move in phase. We can also say that the phase of point C′ lead the phase of point C by one time period or 2π radian. Therefore any point at distance x from point C, the phase of point C lags behind by phase angle



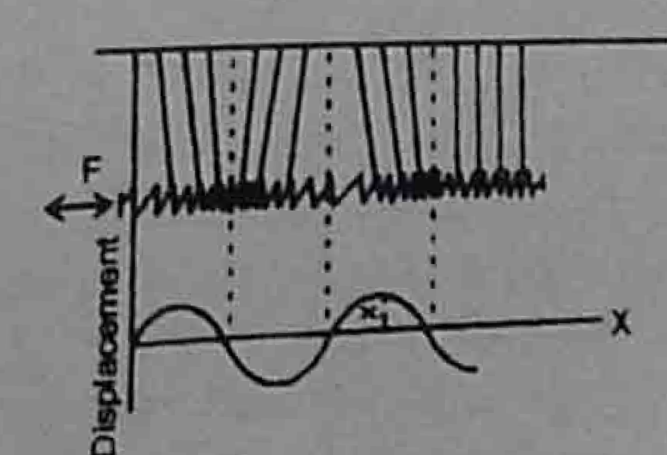
$$\phi = \frac{2\pi x}{\lambda}$$

Similarly if we take other points D and D′ then at these points the medium particals also move in phase. Therefore, there are many points on the waves where the medium particle are vibrating in phase. These points are separated from one another by distances $\lambda, 2\lambda, 3\lambda$ -----. These points may be anywhere on wave, e.g. in the figure P1, P2, P3 are in phase. There is a distance of λ between these points, known as wave length.

Now let us consider points C and D on the wave when C reaches its maximum upward position then the points D reach its maximum downward position. When C begins to go down then D begins to move up. Such points on the wave are separated by $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ - - -. The particle of the mediums at these points are vibrating out of phase.

Longitudinal periodic waves:

Consider a coil of spring. The coil is suspended with the thread as shown in the figure. If an oscillating force F is applied on its one end. Then the force will stretch and compress the spring alternately. Stretch in the spring produces rarefaction and when spring compresses then the compression is produced. Therefore, a series of compression and rarefaction will be produced. Thus we can observe longitudinal periodic wave moving along the spring.



This type of wave generated in the spring is also called compressional wave i.e. particles ... the path of wave move back and forth along the line of propagation of wave. It is, therefore, an eas... way to graph the displacement of the spring element form their equilibrium position

Q.5 Explain the propagation of sound wave in air and also derive Newton's formula for the speed of sound. 1110...

Ans. Speed of Sound in Air:

Sound waves in air are longitudinal waves or compressional waves. These waves travel in the form of compression and rarefaction. The speed of sound waves depends upon the elasticity and the inertia of medium through which it is traveling. Let the medium has elastic constant "E" and density 'ρ' then its speed is given by:

$$v = \sqrt{\frac{E}{\rho}}$$

In general sound travel slowly in gases than in solids.

Newton's formula for speed of sound:

Newton assumed that temperature of the air remains constant when the sound waves propagate through the air. Using this assumption Newton determined the elasticity constant (E) of the air.

The elasticity constant by Hook's law is defined as

$$E = \frac{\text{Stress}}{\text{Strain}}$$

Where stress $= \Delta P$

Bulk strain or volumetric strain $= [\frac{\Delta V}{V}]$

Hence $$E = \frac{\Delta P}{\frac{\Delta V}{V}}$$

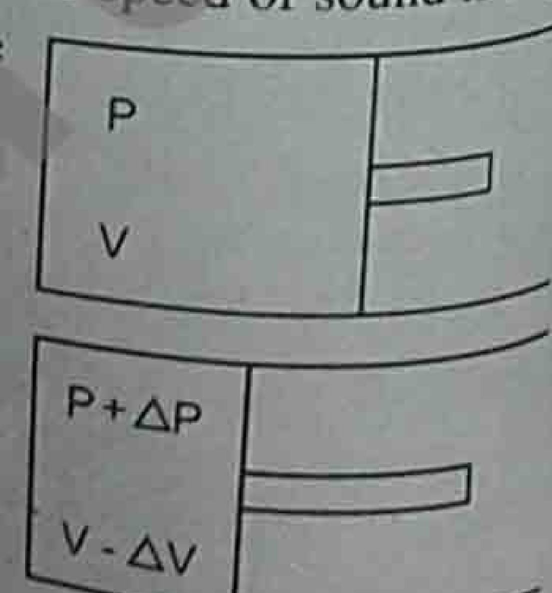
$$\boxed{E = \frac{\Delta PV}{\Delta V}}$$

Newton's derivation for the formula of speed of sound in air:

According to Newton's formula for speed of sound the speed of sound is

$$v = \sqrt{\frac{E}{\rho}}$$

Where E is the modulus of elasticity and ρ is density of medium. The speed of sound is larger in Hydrogen than in oxygen. Also speed of sound increases with the increase of E.



It was assumed by Newton that when sound waves travel in gases then during compression the temperature is increased and during rarefaction temperature is decreased. So during the propagation of sound waves through gases the temperature remain constant. Hence equation of Boyle's law is applicable. i. e

As temperature remains constant, therefore, the variation in pressure and volume is according to Boyle's law:

$$PV = \text{Constant}$$

or $$PV = (P + \Delta P)(V - \Delta V)$$

⇒ Where ΔP and ΔV is very small

$$PV = PV - P\Delta V + \Delta PV - \Delta P\Delta V$$

⇒ The product ΔPΔV are neglected

$$PV = PV - P\Delta V + \Delta PV$$

$$0 = -P\Delta V + \Delta PV$$

$$-\Delta PV = -P\Delta V$$

$$\frac{\Delta PV}{\Delta V} = P$$

$$\Rightarrow \quad \frac{\Delta P}{\frac{\Delta V}{V}} = P$$

$$\boxed{E = P}$$

As speed of sound in a medium is given by

$$v = \sqrt{\frac{E}{\rho}}$$

For air $E = P$

$$v = \sqrt{\frac{P}{\rho}}$$

⇒ The atmospheric pressure of air

$$P = 1.01 \times 10^5 \text{ Pa or N/m}^2$$

⇒ Density of air at room temperature

$$\rho = 1.29 \text{ kg/m}^3$$

$$v = \sqrt{\frac{1.01 \times 10^5}{1.29}}$$

$$v = 280 \text{ m/s}$$

⇒ The above value is less than the value of speed of sound determined experimentally which is 332 m/sec at 0°C.

Q.6 What is Laplace Correction? How did Laplace corrected Newton derivation for the speed of sound? 11108006

Ans. Laplace Correction:

Laplace corrected the Newtòn result by assuming that temperature of the air varies as the sound wave propagate though it. His assumption was quite realistic due to the following reasons.

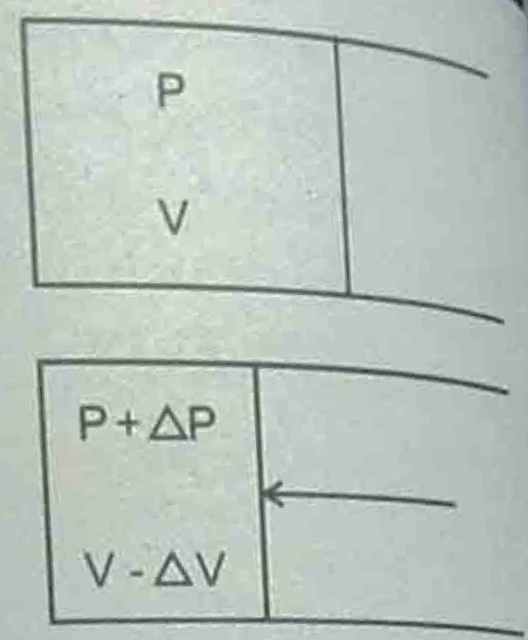
When air is compressed the work is done on the air and hence the temperature will increase. When rarefaction comes the air expand, work is done by the air and hence its temperature will decrease, but no heat transfer take place.

The elastic constant of the air, therefore, can't be determined by using Boyle's law. According to Laplace

$$PV^{\gamma} = \text{constant}$$

where $$\gamma = \frac{C_p}{C_v}$$

The above eq. for two different state can be written as:



$$P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

$$P_1 = P \quad , \quad V_1 = V$$

Putting $P_2 = P + \Delta P$ and $V_2 = V - \Delta V$

$$PV^{\gamma} = (P + \Delta P)(V - \Delta V)^{\gamma}$$

Where $(V - \Delta V)^{\gamma} = [V(1 - \frac{\Delta V}{V})]^{\gamma}$

$$= V^{\gamma}[(1 - \frac{\gamma \Delta V}{V})] \quad \text{By Binomial expansion.}$$

$$PV^{\gamma} = (P + \triangle P)V^{\gamma}(1 - \frac{\gamma \Delta V}{V})$$

$$P = (P + \Delta P)(1 - \frac{\gamma \Delta V}{V})$$

$$P = P - \frac{\gamma P \Delta V}{V} + \triangle P - \frac{\gamma \Delta P \Delta V}{V}$$

$$0 = \frac{-\gamma P \Delta V}{V} + \triangle P - \frac{\gamma \Delta P \Delta V}{V}$$

As $\Delta P \Delta V$ are very small quantities, therefore, the factor $\frac{\gamma \Delta P \Delta V}{V}$ can be neglected.

$$0 = \frac{-\gamma P \Delta V}{V} + \Delta P$$

$$-\Delta P = \frac{-\gamma P \Delta V}{V}$$

$$\frac{\Delta P\, V}{\Delta V} = \gamma P$$

$$\frac{\Delta P}{\frac{\Delta v}{v}} = \gamma P$$

$$\Rightarrow \quad E = \gamma P$$

Hence the speed of sound will be:

$$\therefore \quad \boxed{v = \sqrt{\frac{\gamma P}{\rho}}}$$

γ for air is 1.4

$$v = \sqrt{\gamma}\sqrt{\frac{P}{\rho}}$$

$$v = \sqrt{1.4} \times 280 \text{ m/sec.}$$

$$v = 332 \text{ m/s}$$

$\Rightarrow$ Hence the Laplace formula provide a correct result for the speed of sound in air.

Q.7 What is the effect on the speed of sound with variation with (i)Pressure (ii)Density? 11108007

Ans. Effect of Pressure:

When the pressure of the air increases its volume decreases, therefore, there will be increase in density of the air. In other words $\left(\frac{P}{\rho} = \text{constant}\right)$. Therefore the speed of sound is not affected by the variation of pressure.

Effect of Density:

Speed of sound in air is inversely proportional to the square root of the density.

$$v \propto \frac{1}{\sqrt{\rho}}$$

The above result for two different gases of densities ρ_1 and ρ_2 can be written as

$$\frac{v_1}{v_2} = \sqrt{\frac{\rho_2}{\rho_1}}$$

Therefore, as the density of air increases the speed of sound will decrease. e.g. density of oxygen is 16 time greater than that of hydrogen, therefore, the speed of sound in hydrogen will be 4 times greater than that in oxygen.

Q.8 Discuss the effect of the variation of temperature on the speed of sound in air and show that $v_t = v_o + 0.61t$. 11108008

Ans. As, we know that

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

$$= \sqrt{\frac{\gamma p}{m/V}}$$

$$= \sqrt{\frac{\gamma p V}{m}}$$

$$= \sqrt{\frac{\gamma RT}{m}}$$

$$= \text{constant}\sqrt{T}$$

$$v \propto \sqrt{T}$$

When temperature of gas is increased then due to expansion of gas its density is decreased and velocity of sound is inversely proportional to density. So speed of sound increases with the increase of temperature

Proof:

We know that speed of sound in air is given by:

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

At 0°C and t°C speed of sound is given by:

$$v_t = \sqrt{\frac{\gamma P}{\rho_t}} \quad \text{------------------ (1)}$$

$$v_o = \sqrt{\frac{\gamma P}{\rho_o}} \quad \text{------------ (2)}$$

$$\frac{v_t}{v_o} = \sqrt{\frac{\rho_o}{\rho_t}} \quad \text{------------ (3)}$$

Where $\rho_o = \frac{m}{V_o}$ and $\rho_t = \frac{m}{V_t}$

$V_t = V_o(1 + \beta t)$ where β is called co-efficient of volume expansion and it value is $\frac{1}{273}$ for the gasses.

From the above equations $V_t = \frac{m}{\rho_t}$ and $V_o = \frac{m}{\rho_o}$

$$\frac{m}{\rho_t} = \frac{m}{\rho_o}(1 + \beta t)$$

$$\frac{\rho_o}{\rho_t} = (1 + \beta t)$$

By substituting the value of $\frac{\rho_o}{\rho_t}$ in eq. (3) we get

$$\therefore \quad \frac{v_t}{v_o} = \sqrt{1 + \beta t}$$

or $$\frac{v_t}{v_o} = \left(1 + \frac{t}{273}\right)^{\frac{1}{2}}$$

Using binomial expansion

$$\frac{v_t}{v_o} = 1 + \frac{1}{2}\left(\frac{t}{273}\right) + \ldots\ldots\ldots$$

neglecting higher powers, we get

$$\frac{v_t}{v_o} = \left(1 + \frac{t}{546}\right)$$

$$v_t = v_o + \frac{v_o t}{546}$$

Where $v_o = 332$ m/sec

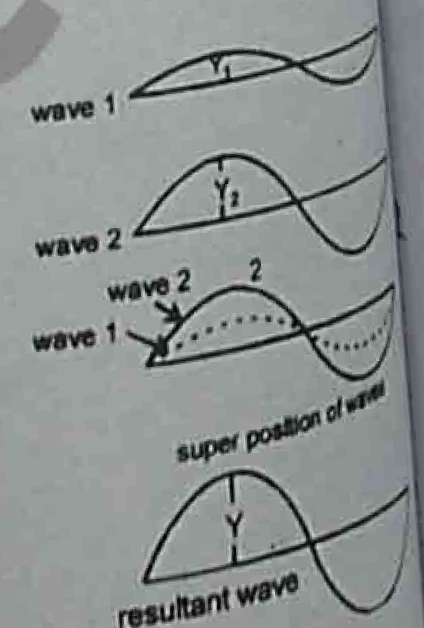
Principally $\therefore v_t = v_o + \frac{332}{546} = v_o + 0.61\,t$

$$v_t = v_o + 0.61\,t$$

Q.9 Explain the superposition of waves. (Board 2008) 11108009

Ans. Principle of Superposition:

It is stated that when a particle of the medium is simultaneously acted upon by two or more waves, than the resultant displacement of the particle is the algebraic sum of the their individual displacement. This is called principle of superposition.



Consider 'n' number of waves which are simultaneously acting on a particle of the medium. Let y_1, y_2 ------------y_n are their individual displacements contributed to the particle. The net displacement due to all of them will be algebraic sum of y_1, y_2------------y_n which is written as.

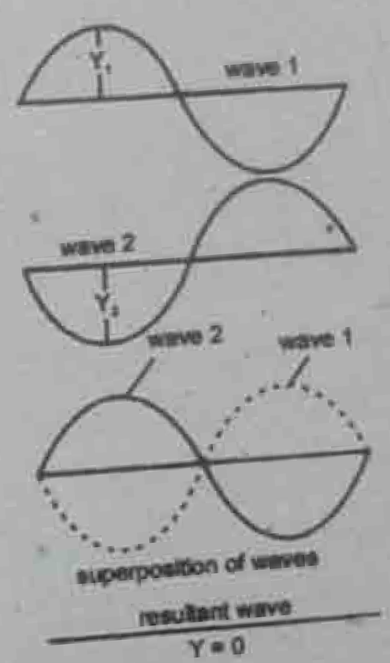
$$y = y_1 + y_2 + \text{-----------}\ y_n$$

Which is the mathematical form of principle of superposition?

Let us consider two waves and study the principle of superposition diagrammatically. Figure (a) shows superposition of two waves of the same frequency which are exactly in phase, Figure (b) shows the superposition of two waves of same frequency which are exactly out of phase.

The three important case of principle of superposition are

i. Two waves having same frequency and traveling in the same direction (interference).
ii. Two waves of slightly different frequencies and traveling in the same direction (Beats)
iii. Two waves of equal frequency traveling in opposite direction (Stationary waves).



Q.10 Explain the interference of waves. What do you mean by constructive and destructive interference? Find their conditions in terms of path difference. (Board 2009) 11108010

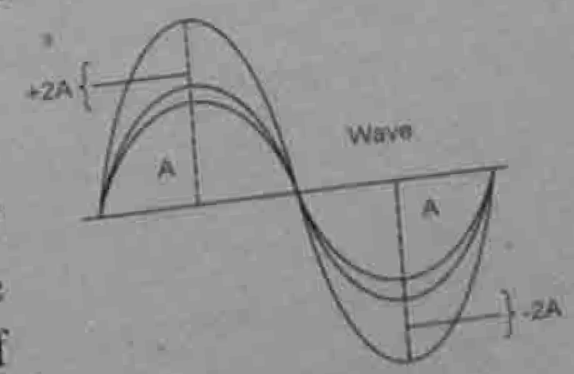
Ans. Interference:

Definition:

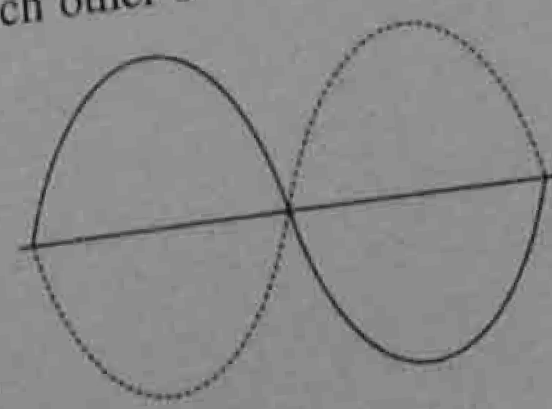
"When two identical waves meet each other in a medium then at some points they reinforce the effect of each other and at some other points they cancel each other's effect. This phenomenon is called interference."

Types:

Constructive interference: The points where the waves support each other's effect are known as points of constructive Interference.
At these points the amplitude of the resultant wave will become equal to the sum of the amplitude of individual waves.
In case of constructive interference of transverse waves crest of one wave falls on the crest of the other similarly trough of one wave falls on the trough of the other. The amplitude of resultant wave can be determined by superposition principle and it become two times the amplitude of single wave.



Destructive interference: The points where the waves cancel each other's effect are known as points of destructive Interference.
At these points the amplitude of the resultant wave will become equal to the difference of amplitude of individual waves.
The two waves will cancel each other's effect only when crest of one wave falls on the trough of the other wave. In this case there will be no resultant wave. Resultant wave have zero amplitude.



"Longitudinal waves also exhibit interference like transverse wave."

Destructive Interference:

Explanation:

An experimental set up to observe interference effect in sound wave is shown in figure 1.

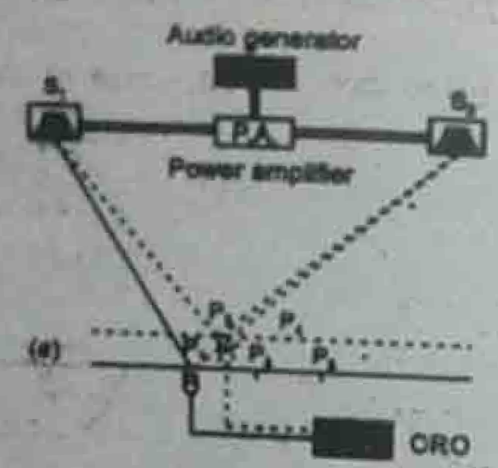


Figure No. 1

Consider two sources of sound in the form of speakers which are driven by an Audio sig[nal] generator. The sound waves from these are emitted in the form of compression and rarefact[ion]. These compression and rarefaction represented by circular lines. The constructive and destruc[tive] interference at the various points can be detected by the microphone attached with sensitive cath[ode] ray oscilloscope. CRO is a high speed graph plotting device. The CRO is an electronic device wh[ich] displays the input signal in the form of waveform on the screen.

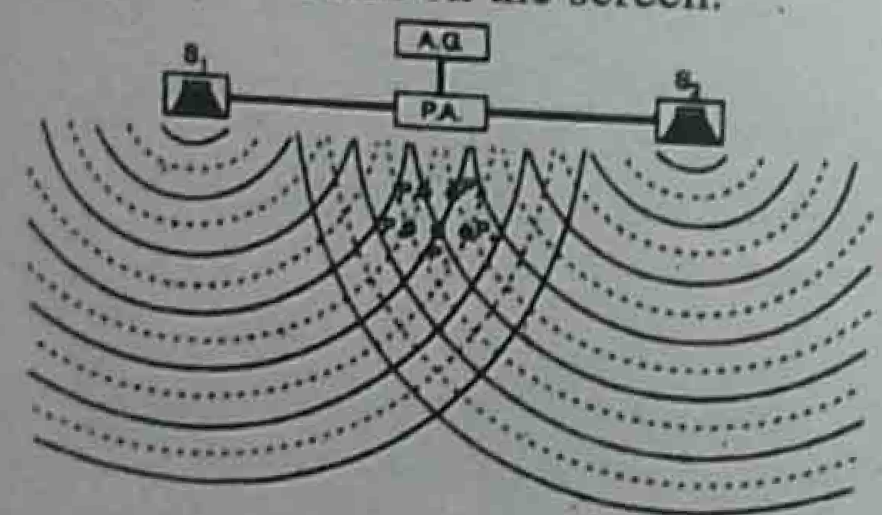


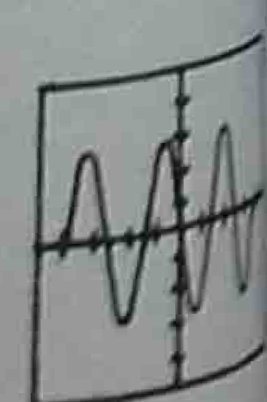
Figure No. 2

Constructive interference:

When two sound waves meet at a point in same phase i.e. compression of one wave falls, on compression of other wave and rarefaction of one wave falls on the rarefaction of other wave. The intensity of sound increases and loud voice is heard. Such type of interference is called constru[ctive] inference. In figure at point P_1, P_3 and P_5 we find that compression meets a compression and rarefaction meets a rarefaction. The displacement of the waves is added up at these points and [the] resultant displacement is produced which is seen on CRO screen.

Condition for constructive interference:

We find that the path difference between waves at point 'P_1' is



$$\Delta S = S_2P_1 - S_1P_1$$

$$\Delta S = 4\frac{1}{2}\lambda - 3\frac{1}{2}\lambda$$

$$\Delta S = \lambda$$

Similarly at points P_3 and P_5 path difference is zero and 'λ' respectively. Thus constructive interference will take place if the path difference between two waves is an integral multiple of wave length 'λ' i.e

$$\Delta s = n\lambda$$

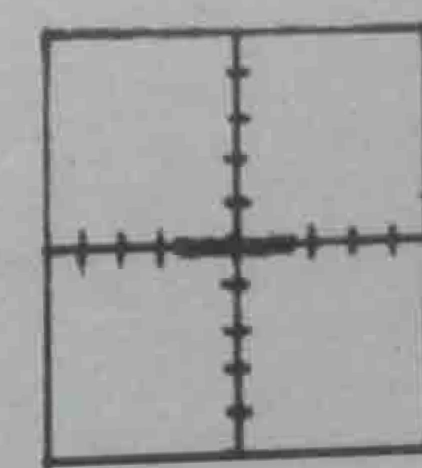
Where $n = 0, \pm 1, \pm 2 \pm 3$

[De]structive interference:

When two sound waves reach at point in opposite phase i.e. compression of one wave falls on [th]e rarefaction of other and vice verse. The intensity of sound decreases or becomes zero and no [so]und is heard. Such type of interference is called destructive interference. In figure (2) at points P_2 [a]nd P_3 we find that compression meets a rarefaction and rarefaction meets a compression that is they [c]ancel each other's effect. The resultant displacement become zero which in seen on the CRO screen.

[C]ondition for destructive interference:

We find that path difference Δs between waves at point P_2 is:



$$\Delta s = s_2p_2 - s_1p_2$$

$$= 4\lambda - 3\frac{1}{2}\lambda$$

$$\Delta s = \frac{1}{2}\lambda$$

Similarly at point P_4, path difference is $-\frac{1}{2}\lambda$ thus destructive [in]terference will take place if the path difference between two waves is odd integral multiple of half [th]e wavelength $\frac{\lambda}{2}$, i.e

$$\Delta s = \left(n + \frac{1}{2}\right)\lambda$$

Where $n = 0, \pm 1, \pm 2 \pm 3$

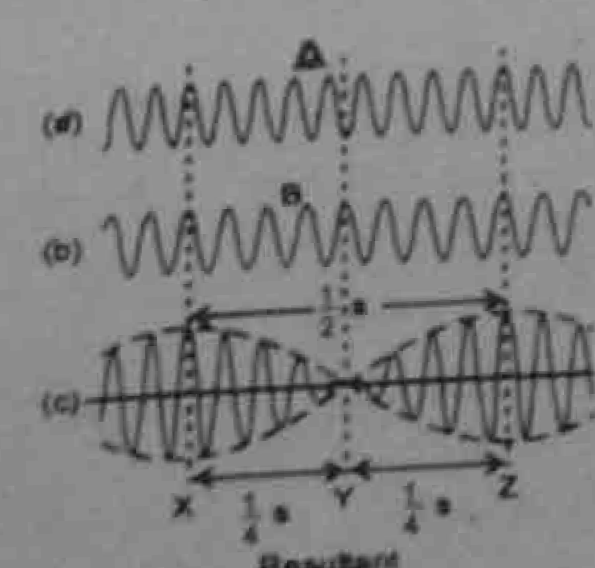
Q.11 What are Beats? How are they produced? Define beat frequency and show that beat frequency is the difference of frequency of two sound waves. 11108011

Ans. Beats:

When two sound waves of slightly different frequency superpose each other then the periodic [var]iation in the intensity of sound is observed. This phenomenon is known as "Beats".

In the laboratory, beats are produced by taking two identical tuning forks making the prongs of [on]e of the tuning forks heavier. In this way a slight frequency difference is created. When two such [tu]ning forks are sounded together then a periodic rise and fall in the intensity of sound is observed [w]hich are known as 'beats'.

[Gr]aphical representation of Beats:



The beats can be represented graphically as shown in the [fig]ure. Figures. (a) and (b) show the wave form of the sound [em]itted by two sources A and B. Fig.(c) represent the resultant [wa]ve form when two waves superpose each other. This wave form [is] obtained by using principle of superposition. The resultant wave [for]m shows the periodic rise and fall in the amplitude and hence [int]ensity of the sound.

Beat Frequency:

Number of beats produced in one second is known as beat frequency. It should be noted beat frequency is equal to the difference in frequencies of the sounded bodies i.e.

$f_A - f_B = \pm n$

Proof:

Consider two identical tuning forks A and B of slightly different frequencies i.e. 32 Hz and Hz. When these are sounded together, they will produce beats. Number of beat produced in second or beat frequency will be 2Hz. This can be described as follows. Let us discuss the even $t = 0$ sec, $t = \frac{1}{4}$ sec, $t = \frac{1}{2}$ sec, $t = \frac{3}{4}$ sec, $t = 1$ sec. At $t = 0$ sec. Let both turning fork start motion simultaneously.

Suppose that prongs of both turning forks at $t = 0$ is at the extreme left position. In position both are sending compression which on the ear reinforce each other and produce in sound or beat at $t = 0$ sec

(i) At $t = \frac{1}{4}$ sec, the prongs of tuning fork A and B have completed 8 vibrations, and vibrations respectively. They are producing compression and rarefaction respectively. On ear they superpose and cancel each other.

(ii) At $t = \frac{1}{2}$ sec the tuning fork A and B have completed 16 vibrations and 15 vibrations prongs of both the tuning are ready to send compression, they superpose each other produce loud sound or beat.

(iii) At $t = \frac{3}{4}$ sec the prongs of tuning fork will complete 24 and $22\frac{1}{2}$ vib. They are in position send compression and rarefaction and reaching on ear they cancel each other and sound minimum intensity is observed.

(iv) At $t = 1$ sec both the tuning fork will complete their 32 and.30 vibration and are ready to their compression which on super position will produce sound of maximum intensity or beat

	¼ sec	2/4 sec	¾ sec	1 sec
f_1= 30HZ	$7\frac{1}{2}$ vib	15 vib	$22\frac{1}{2}$ vib	30 vib
f_2= 32HZ	8 vib	16 vib	24 vib	32vib
Beat	Fall	Rise	Fall	Rise
	No Beat	Beat	No Beat	Beat

From the above discussion it is evident the number of beats in one second are 2, which is equal to frequency difference. When the difference between the frequencies of the two sound waves is more than 10, then it becomes difficult to recognize the beats. Beats are useful in tuning the musical instrument.

Uses of beats

1. Beats are used for tuning the musical instruments.
2. These are used to find unknown frequency of tuning fork.
3. These are used to produce variety in music.

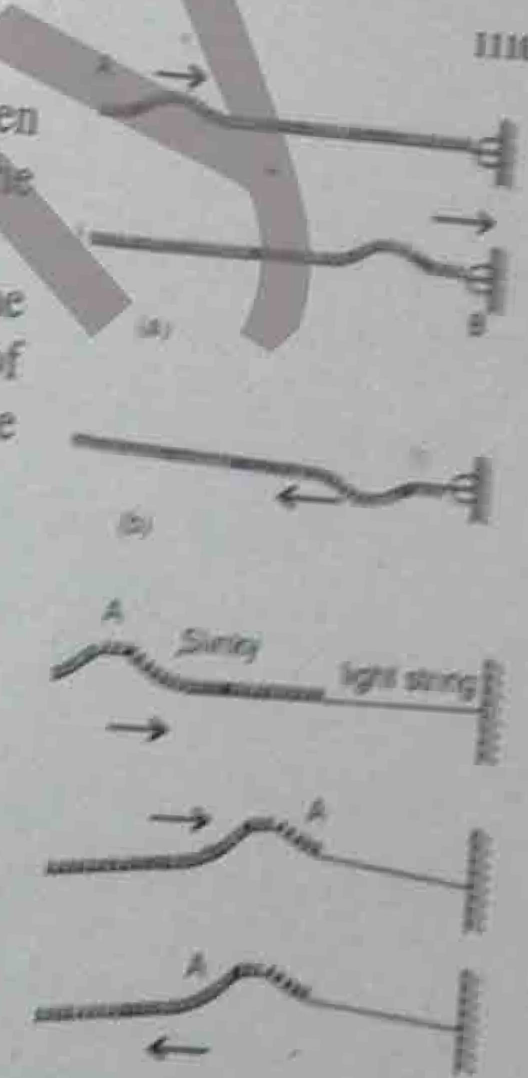
Q.12 What do you mean by reflection of waves? 11108012

Ans. Reflection of Waves:

Reflection is one of the important property of the wave. When any wave travelling through one medium find the boundary of the other medium then it will bounce back.

When the transverse wave are reflected from the boundary of the denser medium then phase of the wave is changed through an angle of 180° i.e. incident crest after reflection will change into trough and vice versa.

When the reflection of transverse waves is takes place from the boundary of rarer medium no phase change will occur .i.e. Incident crest will be reflected as a crest and trough will be reflected as a trough.



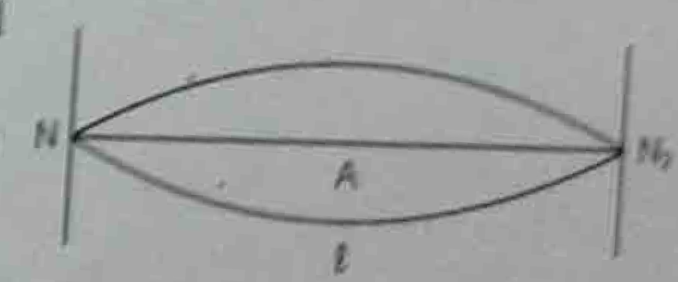
Q.13 What are stationary waves? What are their characteristics? 11108013

Ans. Stationary Waves:

When two waves of the same period, amplitude and speed travel along the same straight line in opposite direction they superimpose, they give rise stationary waves or standing waves.

Nodes: The points on the chord which do not oscillate and remain at rest are known as nodes.

Antinodes: The points on the chord which oscillate with maximum amplitude are known as antinode.

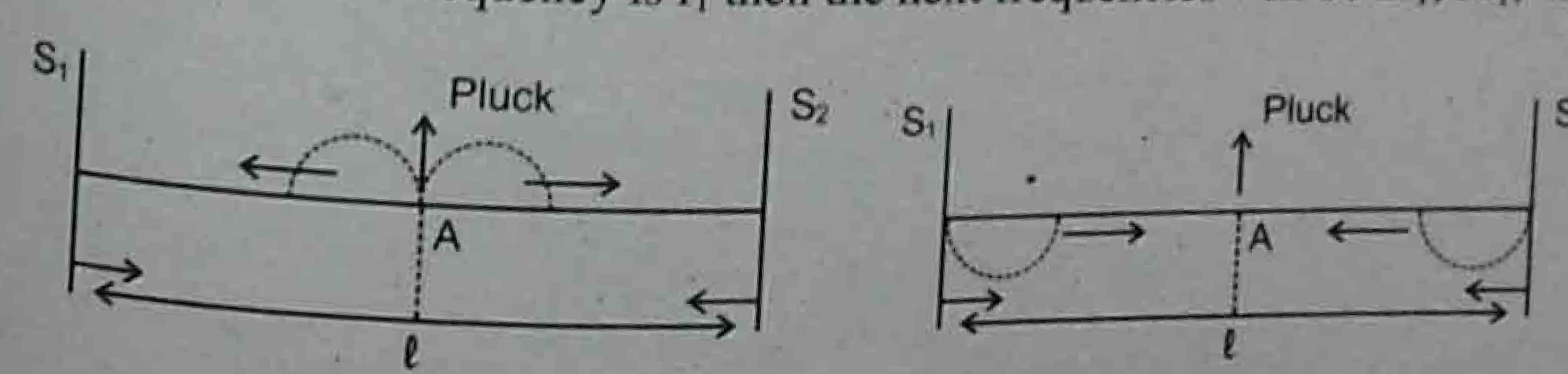


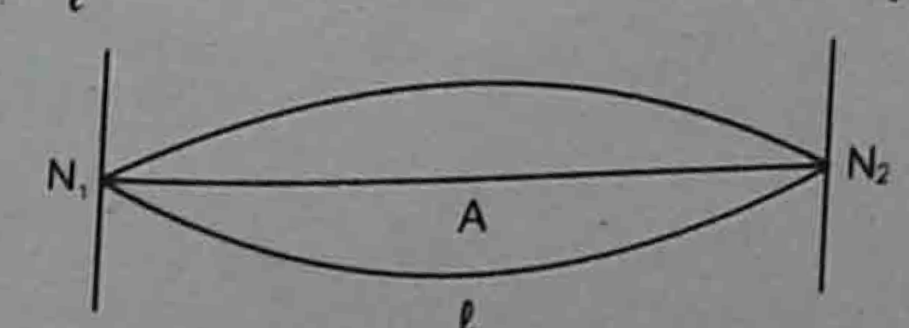
Characteristics Of Stationary Waves Or Standing Waves

1) Stationary waves do not transport energy from one place to another.
2) Stationary waves consists of nodes and antinodes.
3) The distance between two consecutive nodes and antinodes is equal to $\frac{\lambda}{2}$.
4) The distance between a node and its neighbouring antinodes is $\frac{\lambda}{4}$.

Q.14 Explain the principle of quantization of frequency of waves. OR 11108014
Show that stationary waves in a stretched string has discrete value of frequency.
(Principle of quantization of frequency of transverse stationary waves).

According to this principle stationary waves of discrete frequencies can be set up over a stretched string. If the lowest frequency is f_1 then the next frequencies will be $2f_1$, $3f_1$, $4f_1$---------nf_1.





Fundamental mode of vibration:

Consider a string of length 'ℓ' is stretched between two rigid supports S_1 and S_2. Plucking string from the centre give rise two identical waves which after reflection from rigid supports travel along the string in opposite direction. On superposition we will observe that central point always vibrate with maximum displacement and hence will act as "antinode" whereas the extreme ends have minimum displacement behave like "nodes".

From fig $\overline{N_1N_3} = \frac{\lambda_1}{2}$

Where λ_1 is a wavelength of stationary waves.

$$N_1N_2 = \ell$$

$$\frac{\lambda_1}{2} = \ell$$

$$\lambda_1 = 2\ell$$

The speed of the transverse wave over a stretched string is given by

$$v = \sqrt{\frac{F}{m}}$$

Where F is the tension in the string, m is the mass per unit length of the string.

$$v = \lambda_1 f_1$$

$$f_1 = \frac{v}{\lambda_1} \text{ ---------------------- (1)}$$

As $v = \sqrt{\frac{F}{m}}$

$$\lambda_1 = 2\ell$$

Put these values in equation (1) we get

$$\boxed{f_1 = \frac{1}{2l}\sqrt{\frac{F}{m}}}$$

Which is the lowest frequency of stationary waves. It is also known as fundamental frequency or first harmonic.

Frequency of second mode of vibration:

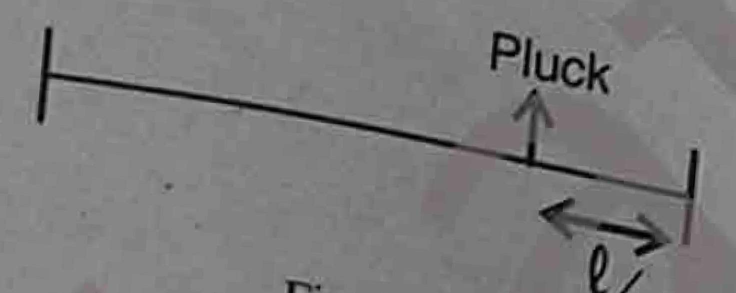


Fig. (1)

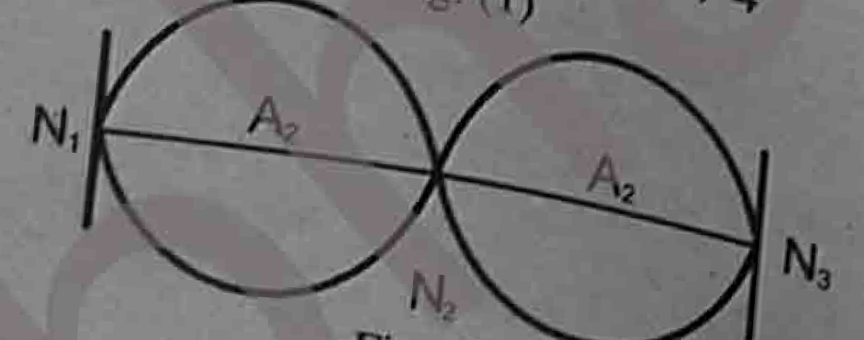


Fig. (2)

On plucking the string from the point one quarter $\left(\frac{1}{4}\right)$ of its total length. The whole string will vibrate as shown in fig (2), in this case.

$$\overline{N_1N_2} + \overline{N_2N_3} = \ell$$

$$\frac{\lambda_2}{2} + \frac{\lambda_2}{2} = \ell$$

$$\lambda_2 = \ell$$

Velocity of the wave.

$$v = \lambda_2 f_2$$

$$f_2 = \frac{v}{\lambda_2}$$

$$f_2 = \frac{1}{\lambda_2} \times v$$

$$f_2 = \frac{1}{l}\sqrt{\frac{F}{m}}$$

Multiply and divide by 2

$$f_2 = 2\left(\frac{1}{2l}\sqrt{\frac{F}{m}}\right)$$

$$\boxed{f_2 = 2f_1}$$

Frequency of Third Mode of Vibration:-

Plucking the string at a distance $\frac{1}{6}\ell$ from one of the support. The whole string will vibrate in 3 segments or loops.

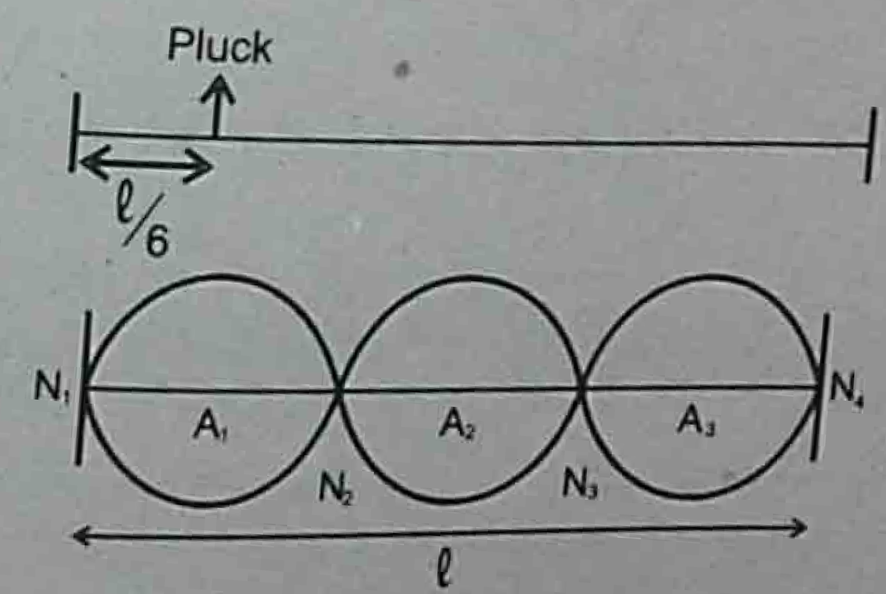


Fig. (3)

In this case

$$\ell = \overline{N_1N_2} + \overline{N_2N_3} + \overline{N_3N_4}$$

$$\ell = \frac{\lambda_3}{2} + \frac{\lambda_3}{2} + \frac{\lambda_3}{2}$$

$$\ell = \frac{3\lambda_3}{2}$$

$$\Rightarrow \quad \lambda_3 = \frac{2\ell}{3}$$

But

$$f_3 = \frac{v}{\lambda_3}$$

$$\Rightarrow \quad f_3 = \frac{1}{\lambda_3} v$$

$$\because \quad v = \sqrt{\frac{F}{m}} \text{ and } \lambda_3 = \frac{2\ell}{3}$$

$$\Rightarrow \quad f_3 = \frac{1}{\frac{2l}{3}} \times \sqrt{\frac{F}{m}}$$

$$f_3 = 3\left(\frac{1}{2l}\sqrt{\frac{F}{m}}\right)$$

$$\boxed{f_3 = 3f_1}$$

Frequency of Nth Mode of Vibration:-

It can be generalized if string vibrates in n segments or loops then the frequency of vibration will be.

$$\boxed{f_n = nf_1}$$

The wavelength of the stationary wave for nth mode of vibration will be

$$\boxed{\lambda_n = \frac{2l}{n}}$$

Therefore as number of loops increases frequency will increase but wavelength will decrease.

Quantization of frequencies:

In any medium stationary waves of all frequencies cannot be set up. The waves having discrete set of frequencies $f_1, 2f_1, 3f_1$ ------- nf_1 only can be set up in the string. This fact is known as quantization of frequencies.

The lowest frequency 'f_1' which produced a stationary waves in a string is called fundamental frequency. Other frequencies which are integral multiple of the fundamental frequency are called harmonics or Overtones. Here f_1 is the fundamental and $2f_1, 3f_1$ are Overtones or harmonics.

Stationary Wave in Air Columns:

A hollow cylindrical tube is known as organ pipe. There are two types of organ pipe.

1. Open end organ pipe.
2. Closed end organ pipe.

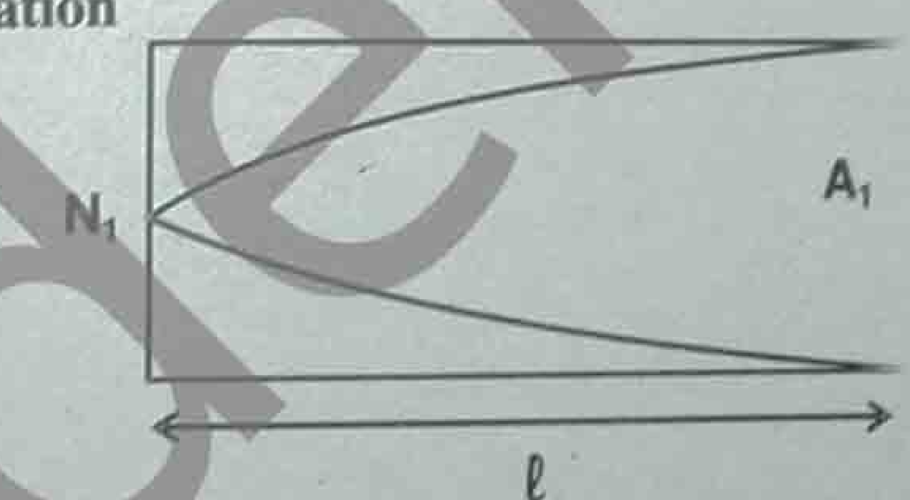
When air is blown from the open end then air column inside the organ pipe will set into vibrations thus giving rise to longitudinal stationary waves.

Q.15 Explain the stationary waves set up in organ pipes. Discuss the various modes of vibration in organ pipe and find the expressions of frequency of different harmonics in (i) Closed end organ pipe (ii) Open end organ pipe. 11108015

Ans. Stationary wave in closed end organ pipe:

When one end of the organ pipe is open and other is closed it is known as closed end organ pipe. When stationary waves are set up in a closed end organ pipe, at the open end air particle is always have maximum displacement act as antinode and at closed end the air particle do not vibrate have minimum displacement act as node. The first stationary wave set up in the organ pipe is shown in the fig. given below:

Fundamental mode of vibration



In this case

$$\overline{N_1A_1} = \ell$$

$$\overline{N_1A_1} = \frac{\lambda_1}{4}$$

When ℓ is the length of the organ pipe

$$l = \frac{\lambda_1}{4}$$

$$\lambda_1 = 4l$$

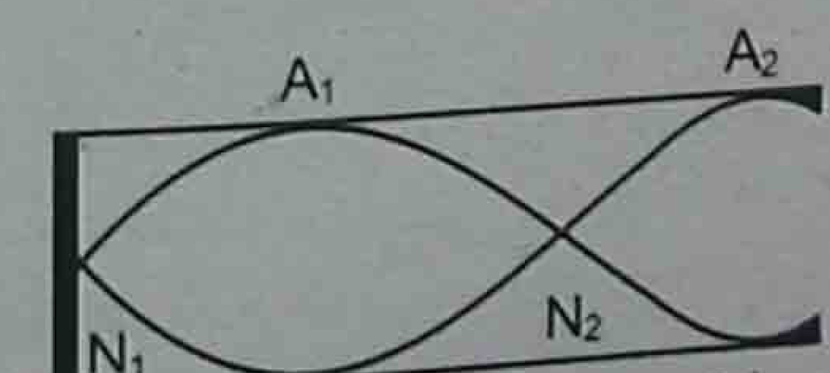
as $\quad v = \lambda_1 f_1$

$$f_1 = \frac{v}{\lambda_1}$$

$$f_1 = \frac{v}{4\ell}$$

Which is the lowest frequency and is known as fundamental frequency where 'v' is the speed of sound in air.

Second mode of vibration:



2^{nd} stationary wave will be as shown. In this case length of the organ pipe 'ℓ' is given by.

$$l = \overline{N_1N_2} + \overline{N_2A_2}$$

$$=\frac{\lambda_2}{2}+\frac{\lambda_2}{4}$$

$$l=\frac{2\lambda_2+\lambda_2}{4}=\frac{3\lambda_2}{4}$$

$$\lambda_2=\frac{4l}{3}$$

But

$$f_2=\frac{v}{\lambda_2}$$

$$f_2=\frac{v}{\frac{4l}{3}}$$

$$f_2=\frac{3v}{4l}$$

$$\boxed{f_2=3f_1}$$

Third mode of vibration:

In this case $\quad l=\frac{\lambda_3}{4}+\frac{\lambda_3}{2}+\frac{\lambda_3}{2}$

$$l=\frac{\lambda_3+2\lambda_3+2\lambda_3}{4}=\frac{5\lambda_3}{4}$$

$$\lambda_3=\frac{4l}{5}$$

$$\lambda_3=\frac{v}{f_3}$$

But

$$f_3=\frac{v}{\lambda_3}$$

$$f_3=5\frac{v}{4l}$$

$$f_1=5f_1$$

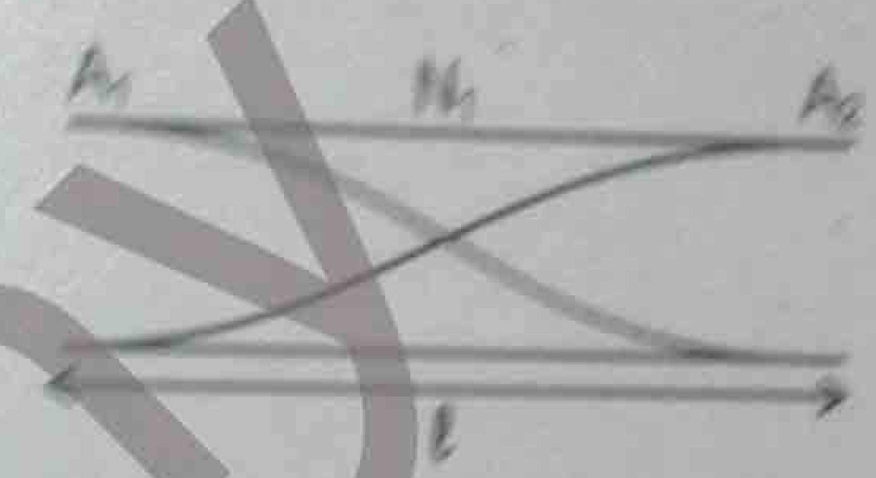
As 'f_1' is fundamental frequency then the harmonics in closed end pipe will have frequencies $3f_1$, $5f_1$, $7f_1$, ---------so on. It means only odd harmonics are present in closed end pipe.

Open End Organ Pipe:

A pipe whose both ends are open is known as open end organ pipe.

When air column resonate or vibrate the amplitude of air particles will be maximum at the ends of organ pipe. Therefore the open ends will always act as antinodes.

Fundamental mode of vibration:



The stationary waves of lowest frequency is shown in the diagram. From the fig.

$$\ell=A_1A_2$$

$$\ell=\frac{\lambda_1}{2}$$

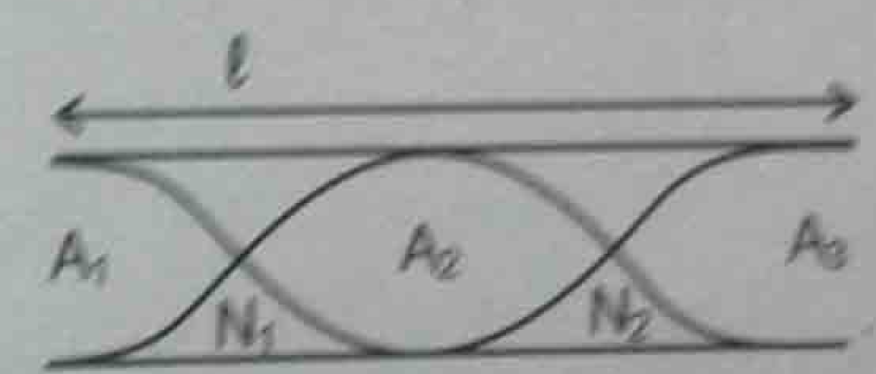
$\lambda_1=2\ell$ We know that

$$v=\lambda_1 f_1$$

$$f_1=\frac{v}{\lambda_1}$$

$$f_1=\frac{v}{2\ell}$$

Second mode of vibration:



In this case:

$$A_1A_2+A_2A_3=l$$

$$\frac{\lambda_2}{2}+\frac{\lambda_2}{2}=l$$

$$l=\frac{\lambda_2+\lambda_2}{2}=\frac{2\lambda_2}{2}$$

$$\boxed{l=\lambda_2}$$

But $\quad f_2=\frac{v}{\lambda_2}$

$$f_2=\frac{v}{\ell}$$

as $\quad \frac{v}{2l}=f_1$

$\therefore \quad f_2=2\frac{v}{2l}$

then $\quad \boxed{f_2=2f_1}$

Third mode of vibration:

In this case

$$\ell=\frac{\lambda_3}{4}+\frac{\lambda_3}{2}+\frac{\lambda_3}{2}+\frac{\lambda_3}{4}$$

$$\ell=\frac{\lambda_3+2\lambda_3+2\lambda_3+\lambda_3}{4}=\frac{3\lambda_3}{2}=\frac{3\lambda_3}{2}$$

$$\lambda_3 = \frac{2\ell}{3}$$

But $$\lambda_3 = \frac{v}{f_3}$$

$$\Rightarrow \quad f_3 = \frac{v}{\lambda_3}$$

$$f_3 = \frac{v}{\frac{2\ell}{3}}$$

$$f_3 = 3\frac{v}{2\ell}$$

$f_3 = 3f_1$

Hence, for nth harmonic we have

$$f_n = n\frac{v}{2\ell}$$

Where n=, 2, 3 ,4 ---------

$f_n = nf_1$

When f_1 is fundamental frequency then harmonics present in an open pipe are $2f_1$, $3f_1$, $4f_1$, and so on. All harmonics are present in open end pipe. This shows that open end pipe is richer in harmonics than close end pipe.

Comparison of fundamental frequencies:

For Closed end organ & open end organ pipe.

$$(f_1)_c = \frac{v}{4\ell}$$

$$(f_1)_o = \frac{v}{2\ell}$$

$$(f_1)_c = \frac{1}{2}\ \frac{v}{2\ell}$$

$$\boxed{(f_1)_c = \frac{1}{2}(f_1)_o}$$

This shows for two pipes of same length, the fundamental frequency in closed pipe is half of the fundamental frequency in open pipe.

Q.16 State and explain Doppler's effect. Discuss its various cases and derive expression for modified frequency in each.

Ans. Doppler's Effect:

The apparent change in the pitch of sound caused by the relative motion between source of sound and the listener is called Doppler's effect.

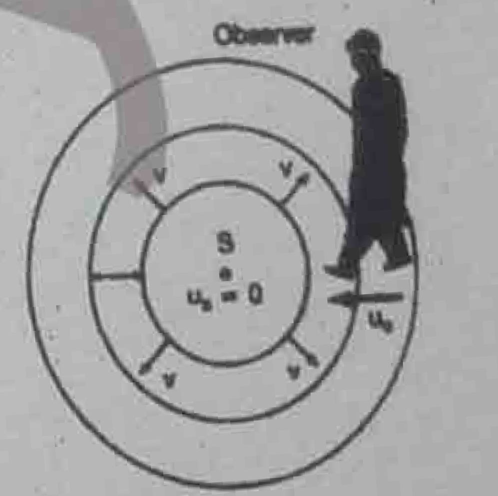
Example:

Suppose a person is standing on a railway platform. The apparent pitch of the whistle of the train increases when the train is approaching the person but when the train moves away from the person the apparent pitch of the whistle of the train decreases.

Case 1:

When the observer moves toward the stationary source:

Suppose a source of sound emits a sound of frequency 'f' and wavelength 'λ'. Let the velocity of sound in the stationary medium is 'v'. If both the source and observer are stationary, then the number of waves received by the observer in one second are.



$$v = f\lambda$$

$$\Rightarrow \quad \lambda = \frac{v}{f}$$

and $$f = \frac{v}{\lambda}$$

If the observer 'A' is moving towards a stationary source with velocity u_0 as shown in the fig, the relative velocity of waves and observer is increased to

$$v-(-u_0) = v+u_0$$

Hence number of waves received in one second or modified frequency 'f_A' is given by

$$f_A = \frac{v+u_o}{\lambda}$$

$$f_A = \frac{v+u_o}{v/f} \qquad \therefore \lambda = \frac{v}{f}$$

$$f_A = \left(\frac{v+u_o}{v}\right)f$$

because $$\frac{v+u_o}{v} > 1$$

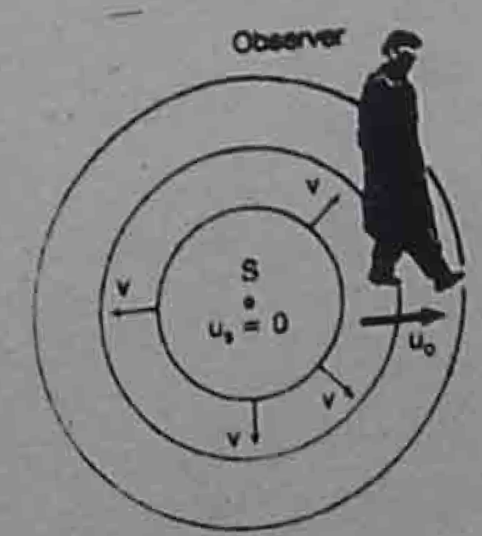
$$\Rightarrow \quad f_A > f$$

Which shows that frequency will be increased.

Case 2:

When listener is moving away from source.

Let us consider the listener is moving away from the source with velocity v, the relative speed of sound with respect to listener is $v - u_0$



$$\therefore \quad v - u_0 = \lambda f_B$$

Where f_B is apparent frequency or modified frequency

$$f_B = \frac{v-u_o}{\lambda}$$

Where $$\lambda = \frac{v}{f}$$

Modified frequency will be

$$\therefore \quad f_B = \left(\frac{v-u_0}{\frac{V}{f}}\right)$$

$$\boxed{f_B = \left(\frac{v-u_0}{v}\right)f}$$

Because $\frac{v-u_0}{v} < 1$

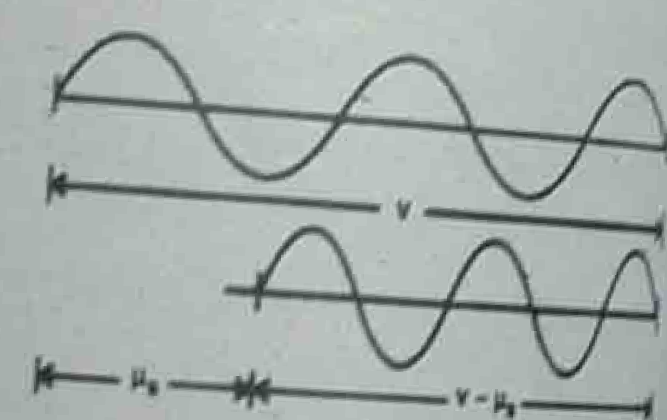
$\Rightarrow \quad f_B < f$

Hence, the pitch of the sound will decrease as listener moves away from the source.

Case 3:

When source is moving toward stationary listener.

The wavelength of sound when both listener and source are stationary is given by:



$$\lambda = \frac{v}{f}$$

When source move toward stationary listener, the waves will be compressed. Therefore, the wavelength will change. The modified wavelength.

$$\lambda_c = \lambda - \Delta\lambda$$

$$= \frac{v}{f} - \frac{u_s}{f}$$

$$\lambda_C = \frac{v-u_s}{f}$$

Speed of sound is given by

$$v = \lambda_C f_C$$

Where f_C is the modified frequency of sound where

$$f_C = \frac{v}{\lambda_C}$$

By putting the value of λ_C, we get

$$f_C = \frac{v}{\left(\frac{v-u_s}{f}\right)}$$

$$\boxed{f_C = \left(\frac{v}{v-u_s}\right)f}$$

Because $\frac{v}{v-u_s} > 1$

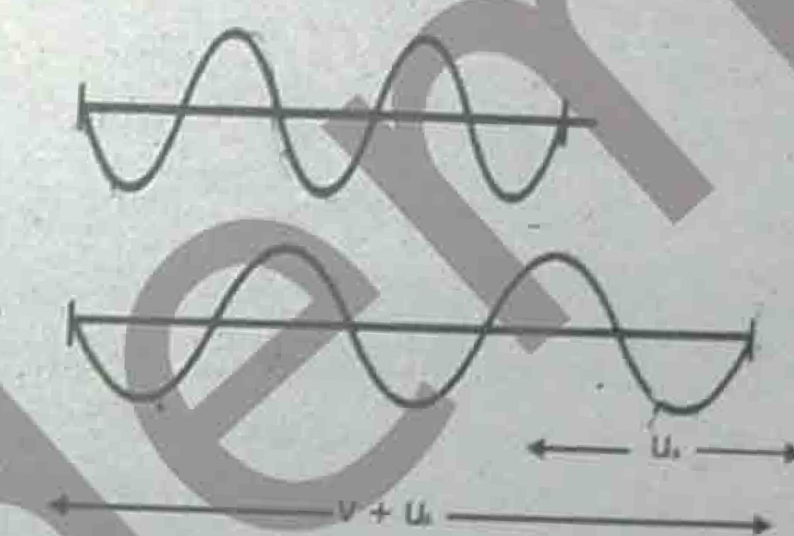
$\Rightarrow \quad f_C > f$

Because modified frequency is greater than actual frequency.
Hence, the pitch of the sound will increase.

Case 4:

When source is moving away from the listener:

When the source moves away from the listener the waves will expand therefore, the new wavelength will be.



$$\lambda_D = \frac{v+u_s}{f}$$

Speed of sound is given by

$$V = \lambda_D f_D$$

$$f_D = \frac{v}{\lambda_D}$$

By putting the value of λ_D, we get

$$f_D = \frac{v}{\left(\frac{v+u_s}{f}\right)}$$

$$f_D = \left(\frac{v}{v+u_s}\right)f$$

Because $\frac{v}{v+u_s} < 1$

$\Rightarrow \quad f_D < f$

Because modified frequency will be less than actual frequency, therefore, the pitch of the sound will decrease.

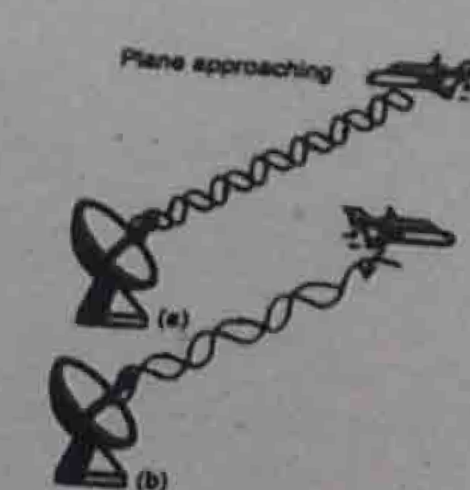
It should be noted that Doppler's effect occurs for all types of waves.

Q.17 Describe various applications of Doppler's effect. **(Board 2009)** 11108017

Ans. Applications of Doppler's effect

Radar system:

Doppler effect is applied in working of radar system. Radar uses radio waves to find the elevation and speed of an aeroplane. Radar is a device, which transmits and receives radio waves. The radio wave transmitted from radar is reflected back from aeroplane and are received by radar. If the aeroplane is moving towards the radar then the reflected wave are shorter. If the plane is moving away from the radar then the wave length of the reflected wave is longer as shown.



Sonar:

Term Sonar (is acronym) stands for sound navigation and ranging. Sonar is the name technique for detecting the presence of objects under water by acoustical echo. Its known mil applications are the detection and location of submarine, control of antisubmarine weapons, hunting and depth measurement of sea.

Astronomer's use:

Astronomers use Doppler's effect to calculate the speed of distant stars and galaxies comparing the line spectrum of light from the star with similar light from a laboratory source, Doppler shift of star's light can be measured and then speed of star can be calculated.

It has been found that stars moving towards the Earth show blue shift this is because the emi waves by the star have shorter wavelength i.e. to the blue end of the spectrum.

It has been found that stars moving away from the Earth show red shift. This is because emitted waves by the star have longer wave length i.e. to the red end of the spectrum.

Speed trap or check:

Microwaves are emitted from the transmitter in short bursts. Each burst is reflected off by a car in the path of microwave. The reflected microwaves are received back as Doppler shifted measuring the Doppler shift the speed of car can be calculated by computer programme.

Short Questions

8.1: What features do longitudinal waves have in common with transverse waves? (Board 2010, 14) 11108018

Ans.

(i) Both types of waves produce disturbance in the medium through which they travel.

(ii) Both transport energy from one place to another.

(iii) In both types of waves the relation between frequency, wavelength and speed of the waves is given by

$v = f\lambda$

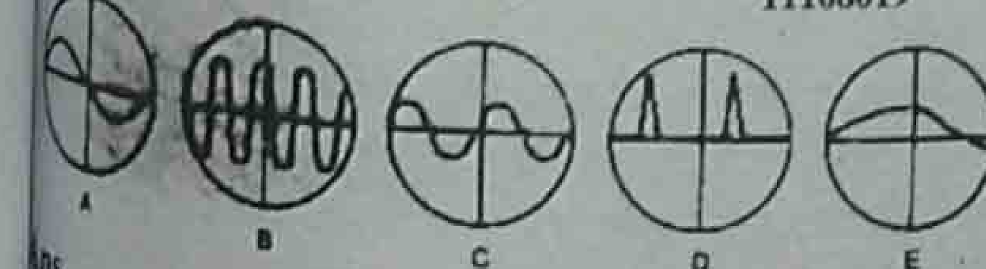
(iv) Both are mechanical waves

(v) In both waves particles oscillate about their mean position.

8.2: The five possible waveforms obtained, when the output from a microphone is fed into the Y-input of cathode ray oscilloscope, with the time base on, are shown in Fig 8.23. These waveforms are obtained under the same adjustment of the cathode ray oscilloscope controls. Indicate the waveform.

(i) Which trace represents the loudest note?

(ii) Which trace represents the highest frequency? 11108019



Ans.

(i) As loudness depend amplitude and hence trace D represents the loudest sound.

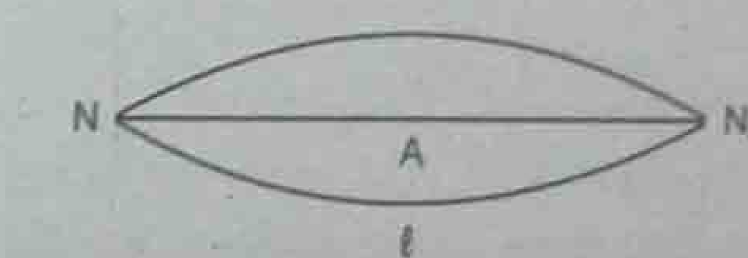
(ii) Trace B represents the highest frequency because in this trace there are maximum number of waves per second.

8.3: Is it possible for two identical waves traveling in the same direction along a string to give rise to a stationary wave. 11108020

Ans. It is not possible for the two identical waves traveling along the same direction to form stationary wave. *Stationary wave is a result of superposition of two identical waves traveling in opposite direction in the same medium.*

8.4: A wave is produced along a stretched string but some of its particles permanently show zero displacement. What type of wave is it? 11108021

Ans. It is a **stationary wave** and points where the particles show permanently zero displacement are known as node.



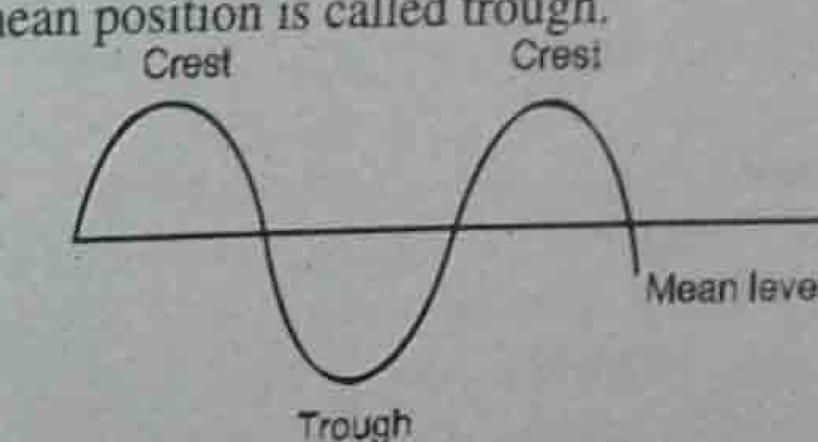
8.5: Explain the terms crest, trough, node and antinodes. (Board 2010) 11108022

Ans. Crest:

It is the portion of transverse wave, which is above the mean position.

Trough:

The portion of transverse wave below the mean position is called trough.

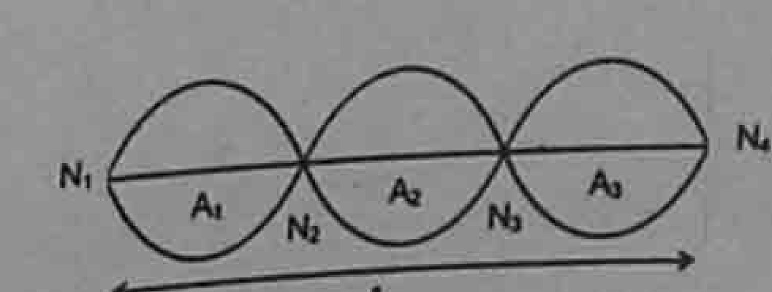


Node:

The point in stationary wave at which amplitude of medium particle is permanently zero is known as node.

Antinode:

The point at stationary wave at which amplitude of medium particle is maximum is named as Antinode.



8.6: Why does sound travel faster in solids than in gases? (Board 2014) 11108023

Ans. The speed V of sound in a medium of modulus of elasticity 'E' and density 'ρ' is given by:

$$V = \sqrt{\frac{E}{\rho}}$$

Although the density of solid is greater as compared to gases but modulus of elasticity for solids is much greater as compared to gases i.e.

$$\left(\sqrt{\frac{E}{\rho}}\right)_{solid} >> \left(\sqrt{\frac{E}{\rho}}\right)_{gas}$$

Hence, sound travel faster in solid than in gases.

8.7: How are beats useful in tuning musical instruments? (Board 2010, 14) 11108024

Ans. We know that number of beats produced per second is equal to difference of frequency of two sounded bodies by tuning a musical instrument we mean to see it to produce a note of desired frequency we take a standard instruments of known frequency. Un-tuned and standard instrument are sounded together. The frequency of un-tuned musical instruments is gradually adjusted till the number of beats become zero.

i.e. $f_A - f_B = 0 \Rightarrow \quad f_A = f_B$

when this happen, the musical instrument will produced the note of desired frequency and it is said to be tuned. In this way beats becomes useful in tuning the musical instruments.

8.8: When two notes of frequencies f_1, and f_2 are sounded together, beats are formed $f_1 > f_2$. What will be the frequency of beats? 11108025

(i) $f_1 + f_2$ (ii) $\frac{1}{2}(f_1 + f_2)$

(iii) $f_1 - f_2$ (iv) $\frac{1}{2}(f_1 - f_2)$

Ans. (iii) $f_1 - f_2$

8.9: As a result of distant explosion, observer senses a ground tremor and then hears the explosion. Explain the difference. (Board 2009) 1110...

Ans. The time difference is due to difference between the speed of sound traveling through earth and air. As speed of sound in solid (earth) is greater than the speed of sound in air hence we will feel tremor first and then we will listen the sound of explosion. Therefore an observer senses grounded tremor first and hears the explosion later.

$$V = \sqrt{\frac{E}{\rho}}$$

8.10: Explain why sound travels faster in warm air than in cold air? (Board 2014) 111...

Ans. We know that speed of sound in air related with its density as.

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

$$v \propto \frac{1}{\sqrt{\rho}}$$

Since density of warm air is less than that of cold air, therefore speed of sound increases as its temperature rises. Hence the sound through warm air travel faster than in cold air.

8.11: How should a sound source move with respect to an observer so that the frequency of its sound does not change? (Board 2014) 1110...

Ans. According to Doppler's effect, the apparent change in frequency of sound produced due to relative motion of the source of sound and observe When source of sound and observer are moving in same direction with same velocity then there will be no relative motion between source and observer. In this case there will be no change in frequency, as observed by observer. If source and listener are moving along the same direction with same velocity then there will be no change in frequency.

Solved Examples

Example 1: Find the temperature at which the velocity of sound in air is two times its velocity at 10 °C. 11108029

Solution: 10 °C = 10 °C + 273 = 283 K

Suppose at T K. the velocity is two times its value at 283 K.

Hence

$$\frac{v_t}{v_{283}} = \sqrt{\frac{T}{283K}}$$

Therefore,

$$\frac{v_t}{v_{283}} = \sqrt{\frac{T}{283K}} = 2$$

T=1132 K or 859 °C

Example 2: A tuning fork A produces 4 beats per second with another tuning fork B. It is found that by loading B with some wax, the beat frequency increases to 6 beats per second. If the frequency of A is 320 Hz, determine the frequency of B when loaded. 11108030

Solution: Since the beat frequency is 4, the frequency of B is either 320 + 4 =324 Hz or 320–4= 316 Hz. By loading B, its freq. will decrease. Thus if 324 is the original frequency, the beat frequency will reduce. On the other hand, if it is 316 Hz, the beat frequency will increase which is the case. So, the original frequency of the tuning fork B is 316 Hz and when loaded, it is 316 – 2 = 314 Hz.

Example 3: A steel wire hangs vertically from a fixed point, supporting a weight of 80 N at its lower end. The diameter of the wire is 0.50 mm and its length from the fixed point to the weight is 1.5 m. Calculate the fundamental frequency emitted by the wire when it is plucked? (Density of steel wire = 7.8 x 10^3 kgm^{-3}) 11108031

Solution:

Volume of wire = Length × Area of cross section

Mass = Volume × Density

Therefore

Mass of wire = Length × Area of cross section × Density

So, mass per unit length m is given by,

m = Density × Area of cross section

Diameter of the wire = D = 0.50 mm = 0.5×10^{-3} m

Radius of the wire = $r = \frac{D}{2} = 0.25 \times 10^{-3}$ m

Area of cross section of wire = $\pi r^2 = 3.14 \times (0.25 \times 10^{-3}\ m)^2$

Therefore

F = w

$m = 7.8 \times 10^3\ kgm^{-3} \times 3.14 \times (0.25 \times 10^{-3}\ m)^2$

$m = 1.53 \times 10^{-3}\ kgm^{-1}$

Weight = 80 N = 80 $kgms^{-2}$

Using the equation

$$f_1 = \frac{1}{2l}\sqrt{\frac{F}{m}}$$

$$f_1 = \frac{1}{2\times1.5m}\sqrt{\frac{80kgms^{-2}}{1.53\times10^{-3}kgm^{-1}}} = 76s^{-1}$$

or $f_1 = 76$ Hz.

Example 4: **A pipe has a length of 1 m. Determine the frequencies of the fundamental and the first two harmonics (a) if the pipe is open at both ends and (b) if the pipe is closed at one end. (Speed of sound in air = 340 ms^{-1})** 11108032

Solution:

a) $f_1 = \frac{nv}{2l} = \frac{1\times340ms^{-1}}{2\times1m} = 170\ s^{-1} = 170\ Hz$

$f_2 = 2f_1 = 2\times170\ Hz = 340\ Hz$

and $f_3 = 3f_1 = 3\times170\ Hz = 510\ Hz$

b) $f1 = \frac{nv}{4l} = \frac{1\times340ms^{-1}}{4\times1m} = 85s^{-1} = 85Hz$

In this case only odd harmonics are present, so

$F_3 = 3f_1 = 3\times85\ Hz = 255\ Hz$

and $f_5 = 5f_1 = 5\times85\ Hz = 425\ Hz$

Example 5: **A train is approaching a station at 90 kmh^{-1} sounding a whistle of frequency 1000 Hz. What will be the apparent frequency of the whistle as heard by a listener sitting on the platform? What will be the apparent frequency heard by the same listener if the train moves away from the station with the same speed? (speed of sound = 340ms^{-1})** 11108033

Solution:

Frequency of source = f_o = 1000Hz

Speed of sound = 340 ms^{-1}

Speed of train = u_s = 90 kmh^{-1} = 25 ms^{-1}

When train is approaching forwards the listener, then using the relation

$$f' = \left(\frac{v}{v-u_s}\right)f$$

$$f' = \left(\frac{340ms^{-1}}{340ms^{-1}-25ms^{-1}}\right)\times1000Hz = 1079.4Hz$$

When train is moving away from the listener, then using the relation

$$f' = \left(\frac{v}{v-u_s}\right)f$$

$$f' = \left(\frac{340ms^{-1}}{340ms^{-1}+25ms^{-1}}\right)\times1000Hz = 931.5Hz$$

Numericals

8.1. The wavelength of the signals from a radio transmitter is 1500m and the frequency is 200KHz. What is the wavelength for a transmitter operating at 1000KHz and with what speed the radio waves travel. 11108034

Data: Frequency of the signal = f_1 = 200KHz.

Wavelength of the signal = λ_1 = 1500m

Frequency of transmitter = f_2 = 1000KHz.

Wavelength of the transmitter λ_2 = ?

Solution: as $\frac{f_1}{f_2} = \frac{\lambda_2}{\lambda_1}$

$\lambda_2 = \frac{f_1}{f_2}\times\lambda_1$

$= \frac{200}{1000}\times1500$

$\boxed{\lambda_2 = 300m}$

$v = \lambda_1 f_1$

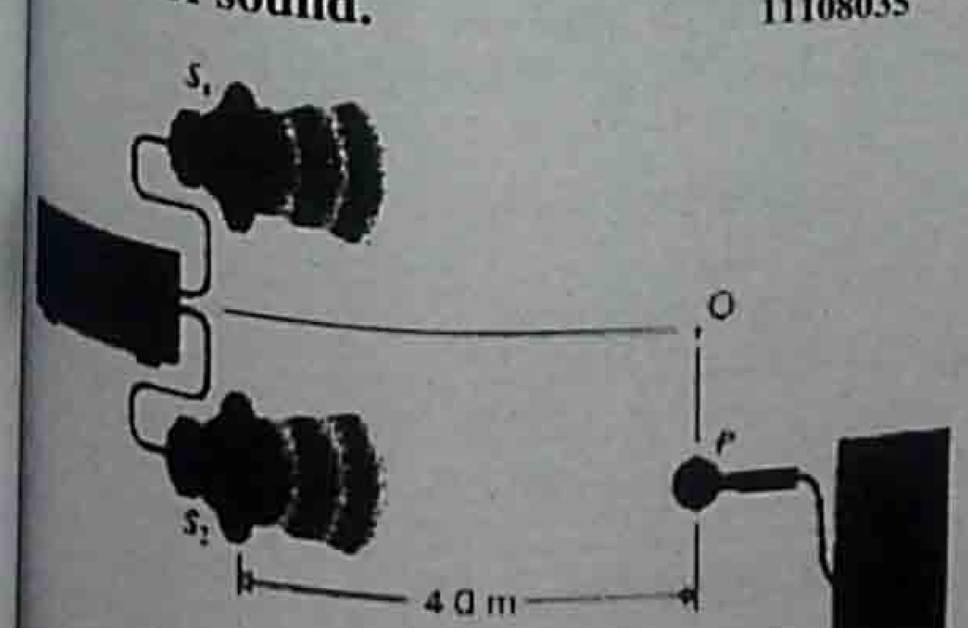
$= 1500\times2\times10^5$

$= 3000\times10^5$

Speed of the Radio wave

$\boxed{v = 3\times10^8\ m/s}$

8.2. Two speakers are arranged as shown in fig. the distance between them is 3m and they emit a constant tone of 344 Hz. A microphone 'P' is moved along a line parallel to and 4.00m from the line connecting the two speakers. It is found that tone of maximum loudness is heard and displayed on the CRO when microphone is on the centre of the line and directly opposite each speakers. Calculate the speed of sound. 11108035



Data:

$s_1p - s_2p = \lambda$

f = 344Hz.

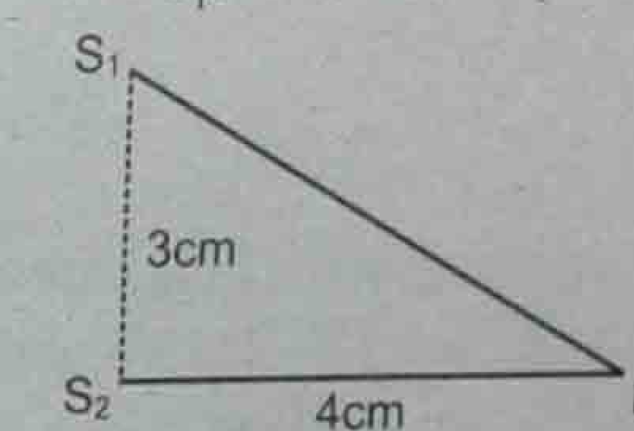
s_1s_2 = 3m

s_2p = 4m

Solution: In right angle triangle s_1s_2p

$\overline{S_1P}^2 = \overline{S_1S_2}^2 + \overline{S_2P}^2$

$\overline{S_1P}^2 = 9+16$



$\overline{S_1P}^2 = 25$

$\overline{S_1P} = 5$

$\lambda = \overline{S_1P} - \overline{S_2P}$

$= 5 - 4$

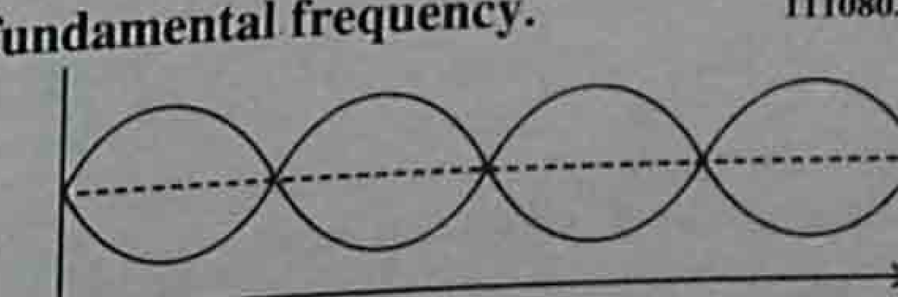
$\boxed{\lambda = 1m}$

$v = f\lambda$

$= 1 \times 344$

$= 344$ m/s

8.3. A stationary wave is established in a string, which is 120cm long and fixed at both ends. The string vibrates in four segments, at a frequency of 120Hz. Determine its wavelength and the fundamental frequency. 11108036



l = 120 cm = 1.2 m

Data: l = 120cm = 1.2m

f_4 = 120Hz.

n = 4

λ_4 = ?

f_1 = ?

Solution:

We know $f_n = nf_1$

$$f_4 = 4f_1$$
$$f_1 = \frac{f_4}{4}$$
$$f_1 = \frac{120}{4}$$
$$f_1 = 30 \text{ Hz.}$$

Also $$\lambda n = \frac{2\ell}{n}$$
$$\lambda_4 = \frac{2\ell}{4}$$
$$= \frac{1.2 \times 2}{4}$$
$$\boxed{\lambda_4 = 0.6\text{m}}$$

8.4 The frequency of the note emitted by a stretched string is 300 Hz. What is the frequency of this note when:
(a) Length of the wave is reduced by one third without changing tension,
(b) The tension is increase by one-third without changing the length of the wire.
(Board 2014) 11108037

Solution: (a)

When tension in the string is constant the speed remains constant original wavelength $= \lambda$

New wavelength $= \lambda_1$

$$\lambda_1 = \lambda - \frac{\lambda}{3} = \frac{2\lambda}{3}$$

New frequency $= f_1 = ?$

$$V = f\lambda = f_1\lambda_1$$
$$300\lambda = f_1 \frac{2}{3}\lambda$$
$$f_1 = \frac{900}{2} = 450\text{Hz}$$

(b) When tension is increase by one-third

$$f_1 = \frac{1}{2l}\sqrt{\frac{F}{m}}$$
$$f_2 = ?$$
$$F_2 = F + \frac{1}{3}F = \frac{4}{3}F$$
$$f_2 = \frac{1}{2l}\sqrt{\frac{\frac{4}{3}F}{m}}$$
$$\Rightarrow f_2 = \sqrt{\frac{4}{3}}\left(\frac{1}{2l} \times \sqrt{\frac{F}{m}}\right)$$
$$f_2 = \frac{2}{\sqrt{3}} f_1$$
$$f_2 = 1.15 \times 300$$
$$f_2 = 346 \text{ Hz}$$

8.5: An organ pipe has a length of 50cm. Find the frequency of its fundamental note and the next harmonic when it is:
(a) Open at both ends.
(b) Closed at one end (speed of sound = 350m/s) 1110803

Data:

$v = 350$m/s

$l = 50$cm $= 0.5$m

(a) $f_1 = ?$ When it is opened at
$f_2 = ?$ both ends.

(b) $f_1 = ?$ When one end is closed
$f_2 = ?$ other end is open

Solution:

(a) When organ pipe open at both ends

then $$f_1 = \frac{v}{2l}$$
$$f_1 = \frac{350}{2 \times 0.5}$$
$$f_1 = \frac{350}{1}$$
$$f_1 = 350\text{Hz}$$
$$\therefore f_2 = 2f_1$$
$$f_2 = 2 \times 350$$
$$f_2 = 700 \text{ Hz}$$

(b) When it is closed at one end

$$f_1 = \frac{V}{4l}$$
$$f_1 = \frac{350}{4 \times 0.5}$$
$$f_1 = \frac{350}{2}$$
$$\boxed{f_1 = 175\text{Hz}}$$
$$f_2 = 3f_1$$
$$f_2 = 3 \times 175$$
$$\boxed{f_2 = 525\text{Hz}}$$

8.6: A church organ consists of pipes, each open at one end, of different lengths. The minimum length is 30mm and the longest is 4m. Calculate the frequency range of fundamental notes. (speed of sound= 340m/s). **(Board 2010) 11108039**

Data:

$l_{min} = 30\text{mm} = 0.03\text{m}$

$l_{max} = 4\text{m}.$

$f_{min} = ?$

$f_{max} = ?$

Solution:

We know for closed end organ pipe.

$$f_1 = \frac{v}{4l}$$

For maximum frequency the length of pipe must be minimum the enforce.

$$f_{max} = \frac{v}{4\,l_{min}}$$

Similarly for producing sound not of minimum frequency.

$$f_{min} = \frac{v}{4\,l_{max}}$$
$$f_{max} = \frac{340}{4 \times 10^{-3}}$$
$$f_{max} = \frac{340 \times 10^{-3}}{120}$$
$$\boxed{f_{max} = 2833 \text{ Hz}}$$
$$f_{min} = \frac{V}{4l_{max}} = \frac{340}{4 \times 4}$$
$$f_{min} = 21 \text{ Hz}$$

8.7: Two tuning forks exhibit beats at a beat frequency of 3Hz. The frequency of one fork is 256Hz. Its frequency is then lowered slightly by adding a bit of wax to one of its prong. The two forks then exhibit a beat frequency of 1Hz. Determine the frequency of second tuning fork. 11108040

Solution:

Number of beats before loading $n = \pm 3$Hg

Frequency of first fork $= f_1 = 256$Hz

Frequency of 2nd fork $= f_2 = ?$

Using formula $f_2 - f_1 = \pm n$

$$f_2 = f_1 \pm n$$
$$f_2 = 253 \text{ or } 259 \text{ Hz}$$

when first fork is loaded with wax then the frequency of first fork must fall below 255, 254, -- therefore number of beats per second decreases on loading first fork which is 1.therefore, frequency of 2nd fork cannot 259Hz hence, the correct frequency of second fork should be equal to

$$f_2 = 253\text{Hz}$$

8.8 Two cars P and Q are Traveling along a motorway in the same direction. The leading car P travels at a steady speed of 12 m/s, the other car Q, traveling at a steady speed of 20 m/s, sound its horn to emit a steady note which P's driver estimates has a frequency of 830 Hz. What frequency does Q's own driver hear? (Speed of sound = 340 m/s). 11108041

Data:

$v_P = 12$ m/sec

$v_Q = 20$ m/s

$f_C = 830$ Hz

$f = ?$

$v = 340$ m/s

Solution:

We know that

$$f_C = \left(\frac{v}{v - u_S}\right) f$$
$$f = \frac{f_C\,(v - u_S)}{v}$$

Where $U_S = v_Q - v_P = 20 - 12 = 8$ m/sec

$$f = \frac{830 \times (340 - 8)}{340}$$
$$f = \frac{830 \times 332}{340}$$
$$f = 810 \text{ Hz}$$

8.9: A train sounds its horn before it sets off from the station and an observer waiting on the platform estimates its frequency at 1200 Hz. The trains then moves off and accelerates steadily. Fifty seconds after departure, the deriver sounds the horn again and the platform observer estimates the frequency at 1140 Hz. Calculate the train speed 50 s after departure. How far from the station is the train after 50s?(Speed of sound=340 m/s). 11108042

Date:

$f = 1200$ Hz

$f_D = 1140$ Hz

$t = 50$ sec

$v_S = ?$

Distance $S = ?$

Solution: we know that

$$f_D = \left(\frac{v}{v + u_S}\right) f$$

$$v + u_S = \frac{v \times f}{f_D}$$

$$u_S = \frac{v \times f}{f_D} - v$$

$$u_S = v\left(\frac{f}{f_D} - 1\right)$$

$$u_S = 340\left(\frac{1200}{1140} - 1\right)$$

$$u_S = 340\left(\frac{1200 - 1140}{1140}\right)$$

$$u_S = \frac{340 \times 60}{1140}$$

$$u_S = 17.9 \text{ m/s}$$

$$\boxed{u_S = 17.9 \text{ m/s}}$$

$$S = v_{av} \times t$$

$$S = \left(\frac{0 + 17.9}{2}\right) \times 50$$

$$S = 448 \text{ m}$$

8.10: The absorption spectrum of faint galaxy is measured and the wavelength of one of the lines identified as the calcium line is found to be 478 nm. The same line has a wavelength of 397 nm when measured in a laboratory.

(a) Is the galaxy moving towards or away from the earth?

(b) Calculate the speed of the galaxy relative to Earth (Speed of light = 3.0×10^8 ms^{-1}). 11108043

Data:

$\lambda_D = 478$ nm

$= 478 \times 10^{-9}$ m

$\lambda = 397$ nm

$= 397 \times 10^{-9}$ m

$c = 3.0 \times 10^8$ m/s

$u_S = ?$

Solution:

$$C = f\lambda$$

$$f = \frac{c}{\lambda}$$

$$f = 7.58 \times 10^{14} \text{Hz}$$

$$f_D = \frac{c}{\lambda_D}$$

$$f_D = 6.28 \times 10^{14} \text{Hz}$$

$$f_D < f$$

So galaxy is moving away form the earth

$$f_D = \frac{c}{c + u_S} \times f$$

$$\frac{f_D}{f} = \frac{c}{c + u_S}$$

$$\frac{f}{f_D} = \frac{c + u_S}{c}$$

$$\frac{f}{f_D} - 1 = \frac{u_S}{c}$$

$$c\left(\frac{f}{f_D} - 1\right) = u_S$$

as $\quad \dfrac{f}{f_D} = \dfrac{\lambda_D}{\lambda}$

$$c\left(\frac{\lambda_D}{\lambda} - 1\right) = u_S$$

As f_D is less than f, so, galaxy is moving away from the earth.

$$C\left(\frac{\lambda_D}{\lambda} - 1\right) = u_S$$

$$u_S = 3 \times 10^8\left(\frac{478}{397} - 1\right)$$

$$u_S = \frac{3 \times 10^8 \times 81}{397}$$

$$u_S = \frac{243}{397} \times 10^8$$

$$u_S = 0.612 \times 10^8$$

$$\boxed{u_S = 6.1 \times 10^7 \text{ m/sec}}$$

Unit 09

PHYSICAL OPTICS

11109001

Q.1 Define Physical Optics.

Ans. The study of laws governing the production, propagation, reception of light and other phenomena related with it, is known as physical optics.

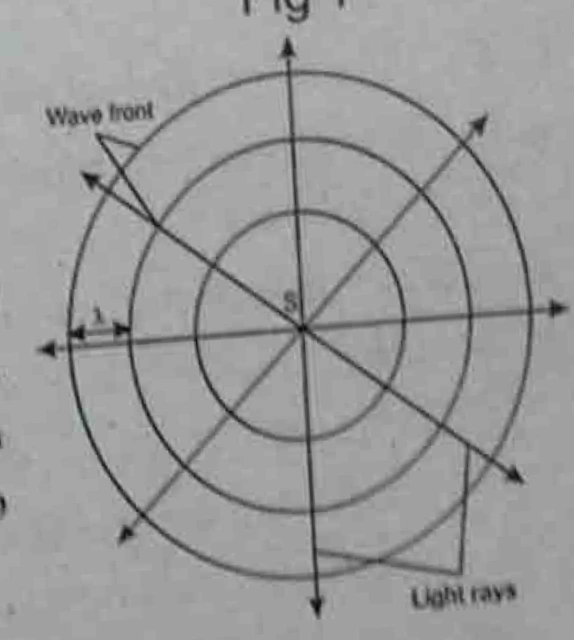
11109002

Q.2 Define wave front and explain it.

Ans. Wave Front:

The surface at which all the particles of medium vibrate in same phase is known as wave front. e.g. In case of water waves any circle drawn with the centre at the point of disturbance is a wave front. A sphere drawn around the point source of light at its center is a spherical wave front.

Fig 1



Explanation:

Consider a point source S of light as shown in fig-1 light propagate in all directions with speed 'c'. After time t, light waves will reach the surface of the sphere with centre as S and radius as r = ct. Every point on the surface of this sphere will be set into vibration by the waves reaching there. Since the distance of all these points from the source is the same, so they are in same state of vibration i.e their phases are same. Such surface is known as spherical wave front. The distance between two consecutive wave fronts is one wave length.

At a very large distance i.e infinity from the source the small portion of spherical wave front become nearly plane such wave front is known as plane wave front.

Q.3 What do you mean by Huygen's principle? Also give its explanation and also define ray. 11109003

Ans. Huygen's Principle:

If we know the shape and location of a wave front at any instant "t", Huygen's principle can be used to determine shape and location of the new wave front at a later time t+Δt. It consists of two parts:

1. Every point on the wave front is considered as a secondary source of light which emit waves, known as secondary wavelets.
2. The new position of the wave front after certain interval of time is obtained by drawing a common tangent to all the secondary waves.

Explanation:

The principle is illustrated in fig 2: AB represents the wave front at any instant t. to determine the wave front at any time t+Δt, draw secondary wavelets with centre at various points on the wave front AB and radius as cΔt where c is speed of the propagation of the wave as shown in fig 2. The new wave front at

Fig 2

Fig 3