**According to new syllabus of all intermediate boards of Sindh.**

***Prof. Rawala's ........***

# PHYSICS

## HELPING BOOK

***For***
***Class XI***
**(All science students)**



## UNIT -12

# Acoustics.

# CONTENTS



**Thoroughly revised and updated 2026 – 2027**

- ***Detailed notes.***
- ***Multiple Choice Questions (M.C.Q's).***
- ***Solution of text book numericals.***
- ***MCQs and solution of numericals from <u>Karachi board</u> past papers.***



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***Unit.12*.....** ✍

# Acoustics

## Sound:

***Q.No.1*: What is sound?**

***Ans*:** Sound is a ***form of energy*** which produces sense of hearing.

OR

Sound is a ***form of energy*** which produces a sensation in our auditory system.

Sound travels in the form of ***longitudinal, mechanical waves.***

***Mechanical waves*** are those waves which **require a material medium** (solid, liquid or a gas) for its propagation.

Mechanical waves **cannot travel** through vacuum.

A mechanical wave originates in the displacement of some portion of an elastic medium, the disturbance is transmitted from one layer to the next. In this way the wave propagates through the medium. The medium itself **does not** move as a whole along with the wave.

Sound waves transfer energy from the vibrating body (source of sound) to the surface on which it falls (e.g. ear drum).

Since sound waves cannot travel through vacuum and there is vast vacuum between the earth and the sun, hence explosions taking place on the surface of the sun **cannot be heard** on the earth.

Similarly, astronauts communicate with each other on the surface of the moon through microphone and a receiver attached to their helmet. This microphone converts sound waves into electromagnetic waves (which **do not require a medium**) and the receiver converts them back into sound waves. (There is no atmosphere i.e. no medium on the moon).

***Q.No.2*: What is audible sound?**

***Ans*:** Human ear responds to sound waves of a limited frequency range.

Sound which can be heard by a normal human ear is called **audible sound**. Normal human ear can hear sound of frequency ***between 20 Hz. and 20,000 Hz*** (***20 kHz***.), hence sound of this frequency range is called **audible sound** and this range of frequencies is called **audible frequency range**.

***Q.No.3*: What are infrasonic waves?**

***Ans*:** Sound waves (Longitudinal waves) of frequency ***less than 20 hz.*** are called infrasonic waves.

***Q.No.4*: What are ultrasonic waves**?

***Ans***: Sound waves whose frequency is ***more than 20 kHz*** (***20,000 Hz***) are called ultrasonic waves.

Normal human ear cannot detect infrasonic and ultrasonic waves; few animals such as whales and bats communicate with each other using ultrasonic waves.

Nowadays ultrasonic waves are widely used in medical field as a diagnostic tool (ultrasound).

# Speed of sound:

***Q.No.1*: What are the factors on which does speed of sound in a medium depend?**

***Ans***: Sound waves travel in the form of **longitudinal compressional** waves. Hence a compressible medium is needed for the propagation of sound waves. Since compressibility of a medium depends upon ***elasticity*** of the medium, therefore, speed of sound depends upon ***elastic*** as well as ***inertial properties*** of the medium.

Speed of sound or any mechanical wave in an elastic medium is basically:

$$\text{Speed of sound} = \sqrt{\frac{\text{Modulus of elasticity of the medium}}{\text{Density of the medium}}}$$

$$\boxed{\upsilon = \sqrt{\frac{E}{\rho}}}$$

Where 'E' is the ***modulus of elasticity*** of the medium (an elastic property) and '$\rho$' is the ***density*** (an inertial property) of the medium.

# Newton's formula for speed of sound:

***Q.No.2*: Give Newton's formula for speed of sound.**
**On what basic assumption does Newton's formula for speed of sound depend?**

***Ans***: Newton assumed that when sound waves travel through a medium the temperature of the surrounding medium ***does not change***. A process in which temperature remains constant is called ***isothermal process***.

***In other words***, according to Newton sound waves travel from one point to another under ***isothermal conditions*** i.e. during the rapid production of compressions and rarefactions temperature of the surrounding air ***does not change***.

Speed of sound in a gas depends upon its bulk modulus "B", and under isothermal conditions the bulk modulus "B" of a gaseous medium such as air, is equal to its pressure "P". Therefore, the speed of sound in air is given by:

$$\boxed{\upsilon = \sqrt{\frac{P}{\rho}}}$$

This formula for speed of sound is known as ***Newton's formula***.

But for mercury barometer $P = \rho g h$ (note that $\rho$ is the density of mercury)

**<u>Speed of sound in air as calculated by Newton's formula</u>:**

Speed of sound in air is given by:

$$\upsilon = \sqrt{\frac{\rho_{mercury}\, g\, h}{\rho_{medium\ (air)}}}$$

**To calculate** speed of sound by Newton's formula at standard temperature and pressure (STP). We know that normal atmospheric pressure is enough to support 76 cm. column of mercury in a barometer. The corresponding atmospheric pressure will be:

$$P = \rho_{mercury}\, g\, h$$

Where $\rho_{mercury} = 13.6$ gm/cm$^3$, g = 980 cm./s$^2$ and h = 76 cm. (in CGS units)

$\therefore$ P = 13.6 × 980 × 76 = **1,012,928 dyne/cm$^2$.**

Density of air at STP is $\rho_{air} = 1.293\times10^{-3}$ gm./m$^3$.

Substituting these values in Newton's formula we get:

$$\upsilon = \sqrt{\frac{1{,}012{,}928}{1.293\times10^{-3}}} = \mathbf{27989.17\ cm./s = 279.8917\ m/s.}$$

Speed of sound in air by Newton's formula comes out to be **<u>279.8917 m/s</u>.** Speed of sound at STP as measured accurately by different experiments is about **<u>320 m/s</u>.**

Speed of sound as calculated by Newton's formula, even with highest degree of accuracy, gave a lesser value as compared to experimentally determined value.

# ***<u>Laplace's correction</u>:***

***<u>Q.No.3</u>: How did Laplace correct Newton's formula for speed of sound? What is the basic assumption on which does the Laplace's correction to Newton's formula for speed of sound depend?***

***<u>Ans</u>:*** The basic assumption on which Laplace's correction to Newton's formula for speed of sound is based is that the propagation of sound takes place under ***<u>adiabatic conditions</u>***, i.e. during the rapid production of compressions and rarefactions, temperature of the surrounding air ***<u>does not remain constant</u>***.

According to Laplace, compressions and rarefactions are produced so **rapidly** and that the **thermal conductivity** of the air is so **poor** (Air is a bad conductor of heat) that the temperature of the surrounding air **does not remain constant**. Due to which propagation of sound through air takes place under ***<u>adiabatic conditions</u>***. Under adiabatic conditions, Bulk modulus "B" of a gaseous medium such as (air) is equal to "$\gamma$ P". Therefore,

$$\boxed{\upsilon = \sqrt{\frac{\gamma P}{\rho}}}$$

Where $\gamma = \dfrac{\text{molar specific heat at constant pressure}}{\text{molar specific heat at constant volume}} = \dfrac{C_p}{C_V}$, for air $\gamma = 1.41$

***<u>Q.No.4</u>: Derive Laplace's formula for speed of sound in air?***

***<u>Ans</u>:*** According to Laplace, propagation of sound through air takes place under ***<u>adiabatic conditions</u>***.

Under adiabatic conditions, Bulk modulus 'B' of a gaseous medium such as (air) is equal to $\gamma$ P. Where '$\gamma$' is the ratio of molar specific heats of a gas at constant pressure '$C_p$' and at constant volume '$C_v$'.

Therefore, the speed of sound in a gaseous medium is given by:

$$\boxed{\upsilon = \sqrt{\frac{\gamma P}{\rho}}}$$

This formula gives us the speed of sound in a gaseous medium such as air; it is known as ***Laplace's formula for speed of sound***.

Substituting the values of $\rho_{mercury}$ = 13.6 gm/cm$^3$, g = 980 cm./s$^2$, h = 76 cm. and $\gamma$ = 1.41 for air, Laplace's formula for speed of sound in air at STP will give us:

$$\upsilon = \sqrt{\frac{1.41\times13.6\times980\times76}{1.293\times10^{-3}}} = \mathbf{33{,}235.2\ cm./s = 332.352\ m/s.}$$

Speed of sound in air at STP as calculated by Laplace's formula gives us accurate value which is in agreement with experimentally determined value.

## ***Factors affecting speed of sound***:

1. Speed of sound is affected by **density** of the surrounding air, It is inversely proportional to square root of density of the medium (air).
2. Speed of sound is affected by the presence of **moisture** in the surrounding air. Hence speed of sound in damp air (having more moisture) is greater than in dry air (having less moisture).
3. Speed of sound in air is ***not affected*** by ***pitch*** and ***loudness*** of sound.
4. It is ***not affected*** by changes in ***pressure,*** because, according to Laplace formula, speed of sound in air depends upon $\sqrt{\gamma P/\rho}$. According to Boyle's law, pressure "P" of a given mass of a gas at constant temperature is inversely proportional to its volume "V", hence if pressure of a gas is doubled its volume will reduce to half but under this condition the density "$\rho$" (mass per unit volume) of the gas will become double its initial value. ***In other words,*** if "P" is doubled "$\rho$" will also be doubled so that the ratio $\sqrt{P/\rho}$ will remain unchanged. Hence changing pressure "P" of the gas will also change its density "$\rho$" such that the speed of sound remains the ***same***.
5. Speed of sound in air ***will change*** if "$\rho$" is changed without changing pressure "P" of the gas. This happens when **temperature "T"** of the gas is changed at constant pressure. According to Charles's law; V $\propto$T (at constant P). When temperature "T" of air increases its ***volume also increases*** (thermal expansion of gases) due to which its ***density "ρ" decreases***. As a result of which its ***speed will increase***. ***In other words,*** speed of sound in air ***increases*** with a ***rise in temperature***. It has been found that speed of sound in air increases by 0.61 m/s per degree rise in temperature. Hence if '$V_o$' is the speed of sound in air at 0°C then its speed '$V_T$' at 'T °C' is given by:

$$V_T = V_o + 0.61\ T$$

1. Speed of sound also changes with wind speed "$V_W$". Speed of sound as received by an observer is ($V + V_W$) in the direction of wind and is ($V - V_W$) against the wind.

# ***Principle of superposition of waves:***

***Q.No.1: State and explain the principle of superposition of waves?***

***Ans:*** According to the principle of superposition of waves:

***"When two or more waves superpose (overlap) each other then the net displacement at any point will be equal to the algebraic sum of displacements due to individual wave at that point".***

Let $\pm y_1$, $\pm y_2$, $\pm y_3$ …….. etc. be the displacements due to first second, third, ……. etc. waves then the net displacement 'Y' at a particular point will be:

$$\boxed{Y = \pm y_1 \pm y_2 \pm y_3 \pm \ldots\ldots\ldots\ldots}$$

Displacement is taken as $+y$ for a crest, whereas, it is taken as $-y$ for a trough.

***In other words***, if a medium is disturbed simultaneously by two crests then the net displacement will be equal to sum of individual displacements, hence a bigger crest will be formed. Similarly, two troughs will form a deeper trough. But a crest and a trough tend to cancel each other's effect.

If amplitude of the crest is more than the amplitude of the trough then a small crest will remain during the overlapping of a crest and a trough, and vice versa.

After the overlapping, the overlapping waves continue their motion with their original amplitude and shape.

# ***Interference of sound waves:***

Two waves are said to be coherent if they are of same frequency.

Two **coherent** sound waves having the **same phase** are said to **interfere constructively** if crest of one wave overlaps the crest of other, and trough of one wave overlaps the trough of the other. Under this condition points at which the two crests overlap a **bigger crest** is formed and the points at which troughs of waves overlap a **deeper trough** is formed. This happens according to the principle of superposition of waves.

Similarly, two **coherent** sound waves having the **same phase** are said to **interfere destructively** if crest of one wave overlaps trough of the other. Under this condition, at these points **net displacement** will be equal to the difference of amplitude of waves. Under this condition displacement due to the crest of one wave tend to cancel the displacement due to trough of the other wave. This happens according to the principle of superposition of waves.

# ***Beats:***

***Q.No.1: What are beats?***

***Ans:*** "The periodic variation in the loudness of sound, produced by two different sources of sound, having **slightly different frequency**, when both are tuned at the same time, is known as **beats**".

Beats are heard because of superposition of sound waves of slightly different frequencies produced by two different sources.

Beats are produced because of slow change in **phase difference** between the two waves.

To understand phenomenon of beats, let us imagine two waves at an instant when waves are in phase, at this instant, waves will interfere constructively and the net amplitude will be maximum, producing loud sound. Since frequency of one of the waves is slightly more than that of the other wave, therefore, this higher frequency wave gets ahead of the other wave due to which phase difference between the waves **increases**. Ultimately the phase difference becomes 180° at some instant, now crest of one wave overlaps trough of the other. Now waves will interfere destructively as a result of which resultant amplitude is **minimum**. As time goes on phase difference between the two waves increases and the net amplitude keeps on increasing so that again the two waves interfere constructively. This process goes on regularly producing **changing amplitude**, due to which **beats** are heard.

***Q.No.2*: What is beat frequency?**

***Ans*:** Beat frequency is the number of beats heard per second.

Beat frequency is equal to the difference in frequency of the two sounds.

$$\boxed{\text{Beat frequency (No. of beats heard per sec.)} = f_1 - f_2}$$

Beats can be heard if the difference in frequency (or beat frequency) is ***not too large***. The maximum number of beats per second that a normal human ear can detect is 7 beats per second. (In other words, for hearing beats the difference in frequency must not be more than 7 Hertz)

***Q.No.3*: What is the main cause of production of beats?**

***Ans*:** Beats are caused because of interference of sound waves of slightly different frequencies. When compressions (Or rarefactions) of the two sounds superpose each other a loud sound is heard but if a compression of one sound overlaps a rarefaction of the other then a low sound is heard.

# Standing or stationary waves:

***Q.No.1*: What are standing or stationary waves? How are they formed?**

***Ans*:** Waves which do not appear to move or appear to be stationary are called ***standing*** or ***stationary waves***.

Points at which a string vibrates with **maximum amplitude** are called ***antinodes***, whereas, the points of **zero amplitude** are called ***nodes***.

- Length of a loop is equal to length of string between two adjacent nodes and is $\lambda/2$ .

***Stationary waves*** are produced when two exactly similar waves travel in opposite direction along the same string and the conditions for superposition of waves are satisfied.

***Q.No.2*: How is one loop formed on a string under tension?**

***Ans*:** When a string under tension is plucked from its midpoint, as soon as the string is released two ***half crests*** travel along the string in opposite directions. One towards **right** and the other towards **left**. These two half crests are reflected from their respective ends as two ***half troughs***. These two half troughs meet in the middle forming a full trough.

***In other words***, after reflection ***a crest becomes a trough*** and vice versa.

The string, therefore, vibrates such that at one instant there is a crest and at the next instant there is a trough on it.

Crest and trough vibrate so rapidly that one loop seems to remain stationary.

Ends of the loop, where displacement of the string is minimum (= 0) are called ***nodes*** and the midpoint of the loop, where displacement of the string is maximum, is called ***antinode***.

Frequency with which the string vibrates so that a loop is formed on it is called ***fundamental frequency*** or ***first harmonic***.

***Q.No.3: What is fundamental frequency or first harmonic?***

***Ans: Fundamental frequency*** or ***first harmonic*** is the ***minimum frequency*** required to produce a stationary wave. If frequency of waves is less than the fundamental frequency no stationary waves are produced.

# Derivation:

***Q.No.4: Derive a formula for fundamental frequency (or frequency required to produce one loop on the string)?***

***Ans:*** Consider a string of length 'L' and of mass 'm' stretched and fixed from both ends. Let 'T' be the tension in the string. If such a string is plucked from its center a stationary loop is formed and the string is said to vibrate in **one loop**. Wave length of the waves when the string vibrates in one loop is given by:

$$\lambda_1 = 2\,L$$

(Length of one loop is half the wavelength $\lambda_1/2 = L$, two loops make one wave)

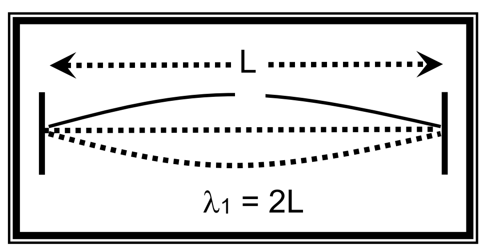
But the frequency with which a string vibrates is given by:

$$f_1 = \frac{v}{\lambda_1} \qquad \text{(For any type of waves } f\lambda = v\text{)}$$

Frequency '$f_1$' with which a string must vibrate so that one loop is formed on it, is called ***fundamental frequency*** or ***first harmonic***. It is the minimum frequency required to produce a stationary wave.

Velocity 'v' with which waves travel along a string, whatever their frequency and wave length is, is given by:

$$v = \sqrt{\frac{T\,L}{m}}$$




Therefore,

$$\boxed{f_1 = \frac{1}{2\,L}\sqrt{\frac{T\,L}{m}}}$$

This formula gives us the frequency required to produce one loop on the string of length 'L' and mass 'm' when the tension in it is 'T'.

***Note that*** if the string vibrates with a frequency other than as calculated by the above formula (slightly higher or lesser) then no stationary wave will be produced and therefore, no well-defined loop will be formed.

Mass per unit length m/L = $\mu$ of a string is called its ***linear density***.

If '$\mu$' is the linear density of the given string then the fundamental frequency is given by:

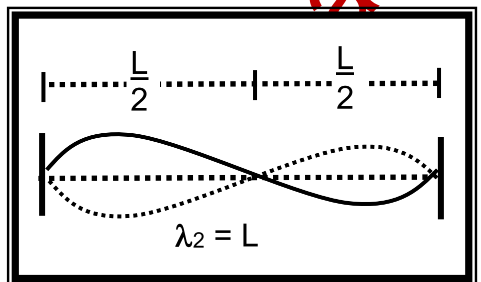
$$\boxed{f_1 = \frac{1}{2\,L}\sqrt{\frac{T}{\mu}}}$$

***Q.No.5**: Derive a formula for frequency required to form two loops on the string (or second harmonic).*

***Ans**:* If a string is properly tuned such that two loops are formed on it then the frequency '$f_2$' with which it now vibrates is called ***second harmonic*** or ***first overtone***. It is given by:

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

But in this case wave length of stationary waves is $\lambda_2 = L$ (Length of each loop L/2 Therefore, $\lambda_2 = L/2 + L/2$).,




$$\boxed{f_2 = \frac{1}{L}\sqrt{\frac{T\,L}{m}}}$$

This equation can also be written as:

$$f_2 = \frac{2}{2\,L}\sqrt{\frac{T\,L}{m}}$$

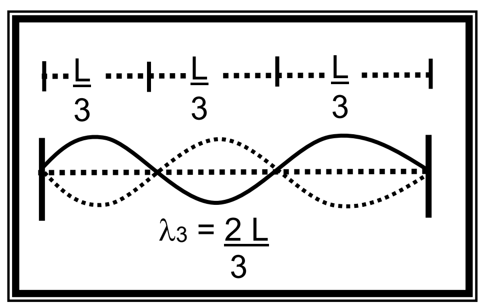
But $\quad f_1 = \frac{1}{2\,L}\sqrt{\frac{T\,L}{m}}$

Therefore, $\quad f_2 = 2\,f_1$

Hence the frequency required to produce **two loops** (or second harmonic or first overtone) is **twice** the **<u>fundamental frequency</u>**.

***Q.No.6**: Derive a formula for frequency required to produce three loops on the string (or third harmonic).*

***Ans**:* If the string is properly tuned such that three loops are formed on it then the frequency '$f_3$' with which it now vibrates is called ***third harmonic*** or ***second overtone***. It is given by:




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

But in this case wave length of stationary waves is $\lambda_3 = \frac{2L}{3}$.(Length of each loop L/3, $\lambda$= Length of two loops) Therefore,

$$\boxed{f_3 = \frac{3}{2\,L}\sqrt{\frac{T\,L}{m}}}$$

But $\quad f_1 = \frac{1}{2\,L}\sqrt{\frac{T\,L}{m}}$

Therefore, $\quad f_3 = 3\,f_1$

Hence the frequency required to produce three loops (or third harmonic or second overtone) is three times the fundamental frequency.

***<u>Q.No.7</u>: Derive a formula for frequency required to produce any number of loops on a string.***

***<u>Ans</u>:*** Frequency with which a string vibrates to produce any number of loops is an integral multiple of ***fundamental frequency***. Hence frequency required to produce 'n' loops will be:

$$\boxed{f_n = n\, f_1}$$

Where $f_1 = \dfrac{1}{2L}\sqrt{\dfrac{TL}{m}}$ OR $f_1 = \dfrac{1}{2L}\sqrt{\dfrac{T}{\mu}}$

Similarly, if 'L' is length of a string then the wavelength of waves when any number of loops 'n' are formed on it is given by:

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

***<u>Q.No.8</u>: What are harmonics?***

***<u>Ans</u>: Harmonics*** are the series of frequencies required to produce stationary waves. Minimum frequency required for producing a stationary wave is called ***fundamental frequency***.

Similarly, frequencies required to produce two, three, four, ……..etc. loops are called second, third, fourth, …….. etc. harmonics.

🗣 Harmonics are integral multiples of fundamental frequency. If frequency is between two harmonics no stationary waves (i.e. no loops) are formed.

***<u>Q.No.9</u>: If tension in a string is doubled what will be the effect on the speed of standing waves in a string? (2010 Karachi Board)***

***<u>Ans</u>:*** Speed 'v' of a standing or stationary wave in a stretched string is given by:

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

This formula shows that speed of waves produced on a stretched string is directly proportional to $\sqrt{T}$. Hence if tension in a string is doubled then speed of stationary waves produced on it increases by $\sqrt{2}$ times its initial value.

## ***<u>Quantization of frequencies</u>:***

Frequencies required to produce stationary waves on a string are always integral multiples of fundamental frequency. This fact is known as **<u>quantization of frequencies</u>** for stationary waves on a string.

# ***<u>Standing waves in open and closed pipes</u>:***

- **Just to remined you** that standing or stationary waves are formed only due to the interference of two waves of **<u>equal frequency</u>** traveling in **<u>opposite direction</u>**. Although the interfering waves **<u>travel / propagate</u>** in opposite directions but the standing wave **<u>does not travel / propagate</u>** and it seems to be **<u>stationary</u>**, that is why it is called **<u>standing</u>** or **<u>stationary wave</u>**.
- Stationary waves can be produced in a string under tension, open and closed pipes etc.

- Minimum frequency required to produce a stationary wave is called **first harmonic** or **fundamental frequency**. If frequency of interfering waves is less than the fundamental frequency **no** stationary waves are produced.

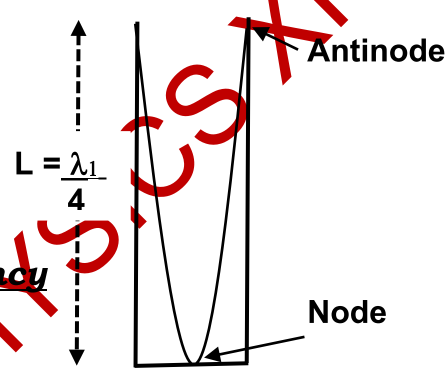
## ***Standing waves in closed pipe*:**

### ***Idea*:**

When sound waves of a particular frequency are produced in a pipe closed at one end and open at the other, air column in the pipe starts vibrating in such a manner that stationary waves are produced, at that instant loud sound is heard. This happens only when at the open mouth an **antinode** and at the closed end a **node** is formed.

- **Node** is that point at which particles of air do not vibrate at all they have **zero amplitude** (due to **destructive interference**), whereas **antinode** is that point at which particles of air vibrate with **maximum amplitude** (due to **constructive interference**).
- When a sound wave traveling in a pipe reaches closed end of the pipe, it is reflected such that if **crest** strikes the closed end then it will be reflected as a **trough** and **trough** is reflected as a **crest**.
- A stationary wave in a pipe closed at one end **always has a node** at the closed end and **an antinode** at the **open end**.

***Fundamental frequency***




- When only **one node** and **an antinode** are formed in a closed pipe, half crest or half trough is formed or **in other words** only a quarter wave is formed (as in this case). (**Note that** a wave has a complete crest and a complete trough),

If L is length of the pipe then in this case, wave length "$\lambda_1$" of the wave will be equal to "4L". At this instant a loud sound is heard. Under this condition air inside the pipe is said to vibrate with **fundamental frequency** '$f_1$'. Hence $L = \lambda_1/4$ or $\lambda_1 = 4L$

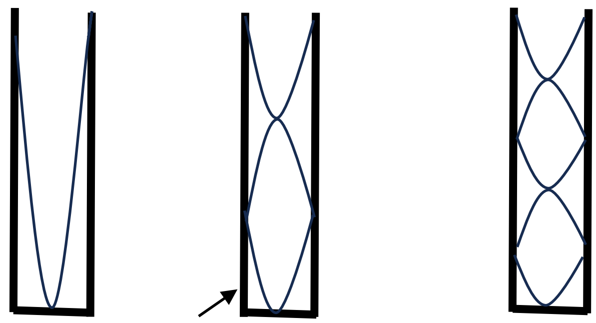
If 'V' is the speed of sound in air then $V = \lambda_1 f_1$

Hence, $f_1 = \dfrac{V}{\lambda_1}$ OR $\boxed{f_1 = \dfrac{V}{4L}}$

***Fundamental mode or first harmonic***

$\lambda_1 = 4\,L$

$f_1 = \dfrac{V}{4\,L}$



***Second harmonic***

$\lambda_2 = 4\,L/3$

$f_2 = \dfrac{3\,V}{4\,L}$ OR $f_2 = 3\,f_1$

***Third harmonic***

$\lambda_3 = 4\,L/5$

$f_3 = \dfrac{5\,V}{4\,L}$

or

$f_3 = 5\,f_1$

- When **two nodes** and **two antinodes** are formed in a closed pipe, such that the **first node** is at the closed end and the **second antinode** is at the open end, In other words, three quarter of a wave is formed. Length of the pipe will be equal to "$3\lambda_2/4$" where "$\lambda_2$" is the wavelength of stationary wave produced. At this instant a loud sound is heard. Under this condition air is said to vibrate in **second harmonic**. Hence $L = 3\lambda_2/4$ OR $\lambda_2 = 4\,L/3$

Since $V = \lambda_2 f_2$ $\therefore$ $f_2 = \dfrac{V}{\lambda_2}$ OR $\boxed{f_2 = \dfrac{3\,V}{4\,L}}$ OR $\boxed{f_2 = 3\,f_1}$

- Similarly, when **three nodes** and **three antinodes** are formed, length of the pipe will be equal to "$5\,\lambda_3/4$" where "$\lambda_3$" is the wavelength of the sound waves produced. At this instant again a loud sound is heard. Under this condition air is said to vibrate in **third harmonic**, and so on. Hence in this case $L = 5\,\lambda_3/4$ OR $\lambda_3 = 4\,L/5$

Since $V = \lambda_3 f_3$ $\therefore$ $f_3 = \dfrac{V}{\lambda_3}$ OR $\boxed{f_3 = \dfrac{5\,V}{4\,L}}$ OR $\boxed{f_3 = 5\,f_1}$

❖ **We notice that** stationary waves can be produced in a closed pipe when frequency of interfering waves is an odd multiple of ***fundamental frequency*** '$f_1$'.
Hence $f_2 = 3\,f_1$, $f_3 = 5\,f_1$, $f_4 = 7\,f_1$, ……
***OR*** $f_n = n\,f_1$ Where n = 1, 3, 5, 7, …..

**Also note that the fundamental wave is of longest wave length and of smallest frequency.**

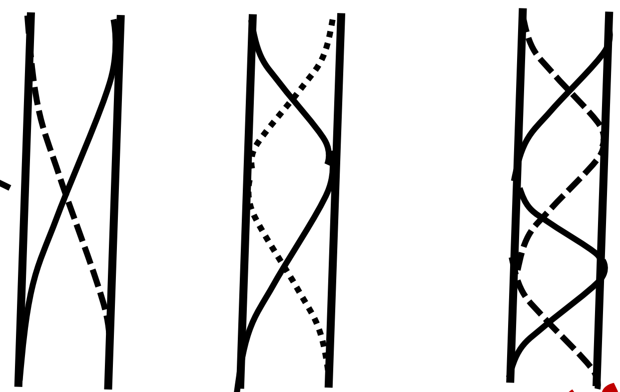
## ***<u>Standing waves in open pipe</u>*:**

***<u>Idea</u>*:** In a pipe open at both ends, stationary waves (Loud sound) can be produced only when **<u>antinodes</u>** are formed at both ends.

***<u>Fundamental mode or first harmonic</u>***

$\lambda_1 = 2L$

$f_1 = \dfrac{V}{2L}$



***<u>Third harmonic</u>***

$\lambda_3 = \dfrac{2L}{3}$

$f_3 = \dfrac{3V}{2L}$

***<u>Second harmonic</u>***

$\lambda_2 = L$

$f_2 = \dfrac{V}{L}$

- When we send sound waves in a pipe open at both ends, starting from a certain low frequency, then a stage will be reached when we hear a loud sound. At this instant a **node** is formed exactly in the middle and **antinodes** are formed at each open end. Stationary wave formed at this instant is said to have ***<u>fundamental frequency</u>***. (**minimum frequency** required to produce a stationary wave). We see that only half wave is formed. ***It means that*** the wave length "$\lambda_1$" of the wave formed will be equal to twice the length "2L" of the open pipe ($\lambda_1 = 2L$). Since frequency of a wave is given by:

$$f = \frac{V}{\lambda} \qquad \text{V is velocity of sound = constant)}$$

Therefore, ***fundamental frequency*** "$f_1$" is given by:

$$f_1 = \frac{V}{\lambda_1} \qquad \text{OR} \qquad \boxed{f_1 = \frac{V}{2L}}$$

- If the frequency of sound waves is gradually increased, then after reaching a certain particular frequency a loud sound is heard again. This is the ***second harmonic***, with two **nodes** inside and two **antinodes** at the open ends of the pipe. This time a full stationary wave is formed. **In other words**, wave length "$\lambda_2$" of the stationary wave formed will equal to "L",($\lambda_2$ = L).

Therefore, ***frequency for second harmonic*** "$f_2$" is given by:

$$f_2 = \frac{V}{\lambda_2} \qquad \text{OR} \qquad \boxed{f_2 = \frac{V}{L}} \qquad \text{OR} \qquad \boxed{f_2 = 2\,f_1}$$

- Similarly for ***third harmonic*** standing wave has one and half wave, for which wave length will be $\lambda_3 = 2L/3$ and frequency required will be :

$$f_3 = \frac{3V}{2L} \quad \text{OR} \quad \boxed{f_3 = 3 f_1}$$

And so on. Hence we conclude that:

$$\boxed{f_n = n f_1} \quad \text{and} \quad \boxed{\lambda_n = \frac{2L}{n}}$$

Where n = 1,2,3,4……

# Doppler's effect:

***Q.No.1*: What is Doppler's effect?**

***Ans***: Doppler's effect is:

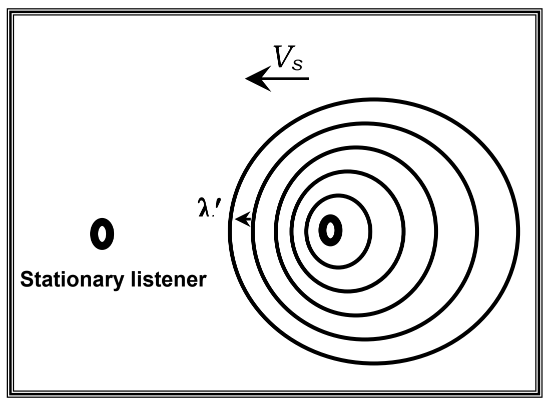
***"The apparent change in pitch of sound due to the relative motion between a source of sound and a listener".***

Pitch of sound depends upon its **frequency**, hence due to the relative motion between its source and the listener, frequency of sound heard by the listener appears to have changed, as a result of which pitch of sound heard by the listener changes.

## Case.1:

***Q.No.2*: Derive a formula for frequency of sound heard when the *source of sound moves towards* a stationary listener.**

***Ans***: When a source of sound emitting sound waves of frequency "$f_s$" moves towards a stationary listener with speed "$V_s$" then the sound waves present between the listener and the source are compressed, hence, their wave length decreases.




Wave length "λ′" of sound heard by the listener is less than the wave length of sound emitted by the source and is given by:

$$\lambda' = \frac{V - V_s}{f_s}$$

The frequency "$f_L$" of sound heard by the listener is given by:

$$f_L = \frac{V}{\lambda'}$$

$$f_L = \frac{V}{\frac{V - V_s}{f_s}}$$

$$\boxed{f_L = \frac{V}{V - V_s} \times f_s}$$

It shows that the frequency of sound "$f_L$" heard by the stationary listener will be ***greater*** than the frequency of sound "$f_s$" emitted by the moving source. The increase in frequency heard depends upon the speed "$V_s$" with which source approaches the listener.

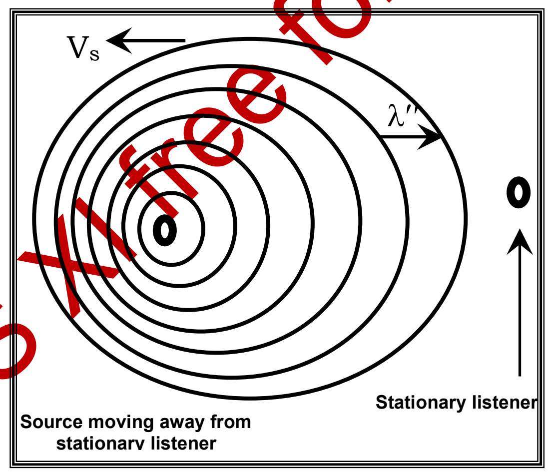
As a result of this increase in frequency, the pitch of sound heard by the listener appears to have ***increased*** (Sound heard becomes **more and more shrill** as the **difference in frequency increases**).

## ***Case.2***:

***Q.No.3*: Derive a formula for frequency of sound heard when the source of sound moves away from a stationary listener.**

***Ans***: When a source of sound emitting sound waves of frequency "$f_s$" moves away from a stationary listener with a velocity "$V_s$", then the wave length of sound heard by the listener **increases** (as the sound waves present between the source and the listener are elongated),and is given by:

$$\lambda'' = \frac{V + V_s}{f_s}$$




The frequency "$f_L$" of sound heard by the listener is given by:

$$f_L = \frac{V}{\lambda''}$$

$$f_L = \frac{V}{\frac{V + V_S}{f_s}} \qquad \boxed{f_L = \frac{V}{V + V_s} \times f_s}$$

Frequency of sound heard by the listener is ***less*** than the frequency produced by the source, hence pitch of sound as heard by the stationary listener also ***decreases*** as a result sound becomes ***grave*** or ***flat***.

***Note that*** due to the motion of the source (above two cases), **wave length** (and **not the relative velocity**) with which sound waves reach the listener changes, as a result of which frequency and therefore, the pitch of sound heard by the listener will change.

In these two cases, the main cause of change in frequency heard by the listener is the change in **wavelength** of sound reaching the listener.

## ***Case 3***:

***Q.No.4*: Derive a formula for frequency of sound heard when the listener approaches a stationary source of sound.**

***Ans***: Let a source of sound emit sound waves of frequency "$f_s$" and wave length "λ", given by

$$\lambda = \frac{V}{f_s}$$

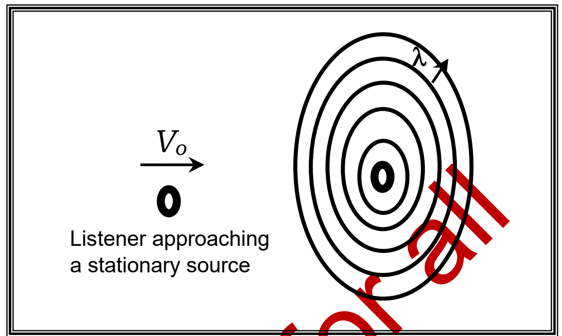
Where "V" is the speed of sound waves.

Let a listener approach the stationary source with a speed "$V_L$" then the relative speed with which sound waves reach him will be "$V + V_L$". Under this condition the frequency of sound "$f_L$" heard by the moving listener will be: (Frequency of waves = speed / wavelength)

$\therefore \quad f_L = \dfrac{V + V_L}{\lambda} \qquad$ But $\lambda = \dfrac{V}{f}$

Therefore, $\quad f_L = \dfrac{V + V_L}{\dfrac{V}{f}}$

$$\boxed{f_L = \dfrac{V + V_L}{V} \times f_S}$$




$f$ is the frequency of sound emitted by the source and $f_L$ is the frequency of sound heard by a listener moving with speed $V_L$ towards a stationary source.

It shows that the frequency of sound "$f_L$" heard by the approaching listener will be ***greater*** than the frequency of sound "$f_S$" emitted by the stationary source. The increase in frequency heard depends upon the speed "$V_L$" with which listener approaches the source. As a result of this increase in frequency the pitch of sound heard by the listener appears to have ***increased*** (Sound heard becomes **more and more shrill** as the **difference in frequency increases**).

## Case 4:

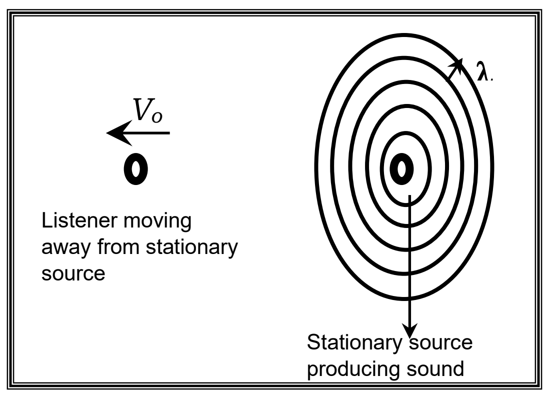
***Q.No.5*: Derive a formula for frequency of sound heard when the listener moves away from a stationary source of sound.**

***Ans*:** When a listener moves away from a stationary source with a speed "$V_L$" then the relative velocity with which sound waves reach him will be "$V - V_L$".
Hence the sound heard by the listener will be of frequency "$f_L$", given by:

$\therefore \quad f_L = \dfrac{V - V_L}{\lambda} \qquad$ But $\lambda = \dfrac{V}{f_S}$

Therefore, $\quad f_L = \dfrac{V - V_L}{\dfrac{V}{f_S}}$

$$\boxed{f_L = \dfrac{V - V_L}{V} \times f_S}$$




It shows that the frequency of sound "$f_L$" heard by the moving listener will be ***less*** than the frequency of sound "$f_S$" emitted by the stationary source. The decrease in frequency heard depends upon the speed "$V_L$" with which listener moves away from the source. As a result of this decrease in frequency the pitch of sound heard by the listener appears to have ***decreased*** (Sound heard becomes grave or less and less shrill as the frequency of sound heard decreases as compared with the frequency emitted).

***Note that*** due to the motion of the listener (above two cases), **relative velocity (wave length is same)** with which sound waves reach the listener changes, as a result of which frequency and therefore, the pitch of sound heard by the listener will change.

The **change in relative velocity** of sound reaching the listener due to the relative motion of the listener is the main cause of change in pitch.

## Case. 5:

***Q.No.6*: Derive a formula for frequency of sound heard when the source of sound and the listener both approach each other while moving along the same line.**

***Ans***: If a source and a listener both are moving towards each other with velocities "$V_S$" and "$V_L$" respectively then the frequency "$f_L$" heard by the listener is given by:

$$f_L = \frac{V + V_L}{V - V_S} \times f_S$$

In this case $f_L > f_S$ , therefore pitch of sound heard by the listener **increase**s due to which sound heard becomes shrill.

## Case 6:

***Q.No.7*: Derive a formula for frequency of sound heard when the source of sound and the listener both move away from each other while moving along the same line.**

***Ans***: If a source and a listener both are moving away from each other with velocities "$V_S$" and "$V_L$" respectively then the frequency "$f_L$" heard by the listener is given by:

$$f_L = \frac{V - V_L}{V + V_s} \times f_S$$

In this case frequency of sound $f_L$ heard by the listener will be less than the frequency '$f_S$' of sound emitted by the source, therefore pitch of sound heard by the listener **decreases** due to which sound heard becomes grave or less shrill.

- If a source of sound moves when a listener is at rest, **frequency** of sound heard changes due to a change in its **wavelength**.
- If a listener moves when the source of sound is at rest, ***frequency*** of sound heard changes due to a change in its **velocity**.

***General formula for frequency of sound heard when the***
***<u>source of sound is in motion</u>***
***and the <u>listener is at rest</u> is:***

$$f_L = f_S\left\{\frac{V}{V \pm V_S}\right\}$$

$-$ ***when source of sound approaches***
$+$ ***when source of sound moves away***

***General formula for frequency of sound heard when the***
***<u>source of sound is at rest</u>***
***and the <u>listener is in motion</u> is:***

$$f_L = f_S\left\{\frac{V \pm V_L}{V}\right\}$$

$+$ ***when listener approaches***
$-$ ***when listener moves away***

***<u>Note that</u>***: Frequency of a wave depends upon its **wave length** and its **velocity**.
**<u>Frequency</u>** of a wave changes if
either its **wave length** is changed at **constant velocity,**
its **velocity** is changed keeping its **wavelength** constant
or both its **wavelength** as well as **velocity** are changed.

***Doppler effect*** takes place in case of light waves also.
By analyzing wave length of light coming from distant stars and galaxies, scientists observed Doppler effect in light waves. They found that wavelength of light coming from distant stars and galaxies **increases** over a long period of time. Wave length of light is found to shift towards longer wavelength, they call it ***<u>red shift</u>***. Observing red shift, they concluded that our universe is ***<u>expanding</u>***.

***<u>Q.No.8</u>: What happens to the pitch of sound of siren of an ambulance which approaches a person standing on the road side?***

***<u>Ans</u>:*** As an ambulance sounding its siren approaches a person standing on the road side, the frequency of sound heard by the person ***increases***, as a result of which <u>pitch of sound also increases</u>. Due to increase in pitch of sound, sound of siren heard becomes more and more shrill as the ambulance approaches the person.

***<u>Reason</u>***: ***wavelength*** of sound waves present between the ambulance and the person ***decreases*** as the ambulance approaches the person, due to which ***frequency*** of sound of siren heard by the person standing by the road side appears to ***increase*** and the sound heard becomes ***more and more shrill***.

***Q.No.9*: What happens to the pitch of sound of siren of an ambulance heard by a person traveling in a car such that the car and the ambulance both move *towards each other*?**

***Ans*:** If an ambulance sounding its siren approaches a person travelling in a car moving towards the ambulance, the frequency of sound of siren heard by the person ***increases***, as a result of which pitch of sound heard will also ***increase***. Sound heard will become ***more and more shrill*** as the ambulance and the person both approach each other.

***Q.No.10*: What happens to the pitch of sound of siren of an ambulance heard by a person traveling in a car such that the car and the ambulance *move away from each other*?**

***Ans*:** If an ambulance sounding its siren and a person travelling in a car move away from each other, the frequency of sound of siren heard by the person ***decreases***, as a result of which pitch of sound heard will also ***decrease***. Sound heard will become ***less and less shrill*** as the ambulance and the person both move away from each other.

# *Applications of Doppler's effect*:

***Q.No.11*: Give some applications of Doppler's effect.**

***Ans*:**

- With the help of Doppler's effect speed of approaching or receding vehicles can be found. For this purpose, traffic police use a device based on this idea.
- Radar waves after reflection from a plane etc. on reaching its antenna show a change in frequency. This change in frequency depends upon the speed with which a plane approaches or moves away from the radar station. Hence a radar operator can easily determine the movement and intention of the plane.
- Ships are equipped with a device called "SONAR". It works on the principle of Doppler's effect. It detects the presence of underground rocks and submarines etc.
- Light also show Doppler effect provided speed of source of light or that of the observer is very high.
- Currently ultrasound radiations have been used for the diagnosis of various medical problems. It is based on Doppler's effect.

# *Sonic boom*:

***Q.No.1*: What is sonic boom? How is sonic boom produced?**

***Ans*:** When speed of a source of sound '$V_S$" is comparable to the speed 'V' of sound then the source of sound and the waves of sound move together in the same direction. As a result of which the number of waves produced in front of the source keeps on ***increasing***. Due to which a plane wave front of highly compressed air is formed which moves in front of the source of sound.

If the source of sound moves faster than sound i.e. $V_S > V$, then the plane wave front takes the shape of a cone with the fast-moving source at its apex. Air in the cone shaped wave front is highly compressed. This cone shaped wave front of highly compressed air is known as ***shock wave.***

Hence supersonic air crafts, such as F-16 or Mirage fighter planes, produce shock waves of such a strength that a loud explosion is heard. This loud explosion is called '***Sonic boom***'. Supper sonic planes produce double sonic booms, one from the shock waves produced in the front and the other to the rear of the plane.

## Section–A Multiple-Choice Questions MCQs:

***Q.No.1***: The speed v of a wave represented by $y = A \sin (kx - \omega t)$ is:

(A) k/ω (B) ω /k (C) ω k (D) 1/ ω k

***Q.No.2***: Two sound waves are

$y = \sin (kx - \omega t)$ and $y = \cos (kx - \omega t)$.

Phase difference between the two waves is:

(A) π/2 (B) π /4 (C) π (D) 0

***Q.No.3***: If $v_a$, $v_h$ and $v_m$ are speed of sound in air, in hydrogen gas and in a metal at the same temperature, then:

(A) $v_a > v_h > v_m$ (B) $v_m > v_h > v_a$

(C) $v_h > v_m > v_a$ (D) $v_h > v_a > v_m$

***Q.No.4***: Speed of sound in air at STP is 332 m/s. If the pressure becomes double at the same temperature, the speed of sound becomes:

(A) 1382 m/s. (B) 664 m/s.

(C) 332 m/s. (D) 166 m/s.`

***Q.No.5***: How does the speed of sound "v" in air depend on the atmospheric pressure "P":

(A) $v \propto P^0$ (B) $v \propto P^{-1}$ (C) $v \propto P^2$ (D) $v \propto P^1$

***Q.No.6***: The speed of sound in a gas is proportional to:

(A) square root of isotheral elasticity.

(B) square root of adiabatic elasticity.

(C) isotheral elasticity.

(D) adiabatic elasticity.

***Q.No.7***: Length of a pipe closed at one end is "L". In the standing waves whose frequency is 7 time the fundamental frequency, what is the closest distance between nodes?

(A) $\frac{1}{14}$ L (B) $\frac{1}{7}$ L (C) $\frac{2}{7}$ L (D) $\frac{4}{7}$ L

***Q.No.8***: A 620 Hz frequency song of an ice cream trolley approaches with speed "v" to a boy standing at the door of his house is heard with frequency "$f_1$". If the trolley is stopped and the boy approaches the ice cream trolley with the same speed "v" the boy now hears sound of frequency "$f_2$", choose the correct statement

(A) $f_1 = f_2$ both are greater than 620 Hz.

(B) $f_2 > f_1 > 620$ Hz.

(C) $f_1 = f_2$ both are lesser than 620 Hz.

(D) $f_1 > f_2 > 620$ Hz.

***Q.No.9***: The speed of sound in a gas in which two waves of wavelength 50 cm and 50.4 cm produce 6 beats per second is:

(A) 338m/s (B) 350m/s (C) 378 m/s (D)400 m/s

***Q.No.10***: The speed of a wave in a medium is 760 m/s. If 3600 waves are passing through a point in the medium in 2 minutes, then its wave length is:

(A) 13.85 m. (B)25.3 m. (C)41.5 m. (D)57.2 m.

***Q.No.11***: Human beings can hear sound of frequency: (***2005 Karachi Board***)

(A)5 Hz. (B)5000Hz. (C)25000 Hz (D)50000 Hz.

***Q.No.12***: The velocity of sound in a gas increases with: (***2005 Karachi Board***)

(A) Temperature (B) Pressure

(C) Loudness (D) frequency.

***Q.No.13***: Frequencies which are multiples of fundamental frequency are called:

(***2005 Karachi Board***)

(A) Beat frequency (B) Nodal frequency.

(C) Harmonics (D) Doppler effect

***Q.No.14***: Which of the following is not the property of sound waves?

(***2005 Karachi Board***)

(A) Interference. (B) Diffraction.

(C) Polarization. (D) Refraction.

***Q.No.15***: Beats are produced due to:

(***2006 Karachi Board***)

(A) Diffraction. (B) Interference.

(C) Polarization. (D) Refraction.

***Q.No.16***: Which of the following represents longitudinal waves?:(***2006 Karachi Board***)

(A) light waves. (B) sound waves.

(C) Radio waves. (D) X-rays.

***Q.No.17***: The speed of sound is highest in:

(***2007 Karachi Board***)

(A) solid. (B) liquid. (C) gas (D) vacuum

***Q.No.18***:The voice of two persons having the same pitch and loudness can be recognized due to the characteristic of sound known as: (***2007 Karachi Board***)

(A)Beats (B)Quality (C)Frequency (D)Intensity

***Q.No.19***: The frequency of a simple pendulum is given by: (***2008 Karachi Board***)

(A) $\nu = 2\pi\sqrt{g/L}$ (B) $\nu = 2\pi\sqrt{L/g}$

(C) $\nu = \frac{1}{2\pi}\sqrt{L/g}$ (D) $\nu = \frac{1}{2\pi}\sqrt{g/L}$

***Q.No.20***: If mass of a body suspended from a spring is increased to 4 times, the period of vibration of the body will be:

(***2008, 2007 Karachi Board***)

(A) 4 times. (B) 2 times

(C) $\sqrt{2}$ times (D) same as before

***Q.No.21***: If the fundamental frequency of vibration of a string fixed at both ends is 50Hz. The fourth harmonic will be:

(***2008 Karachi Board***)

(A)100 Hz (B)150 Hz (C)200 Hz (D)250 Hz

***Q.No.22***: If the tension of a stretched string is increased 4 times, the speed of the transverse wave in it will increase:

(***2009 Karachi Board***)

(A)4 times (B)8 times (C)2 times(D)16 times

***Q.No.23***: The velocity of sound has maximum value in:(***2009 Karachi Board***)

(A)Solids (B)liquids (C)gasses (D)free space

***Q.No.24***: This is compressional wave

(***2011 Karachi Board***)

(A) Light waves. (B) Sound waves.

(C) Radio waves. (D) X-rays.

***Q.No.25***: If two tuning forks of frequencies 256 Hz. and 260 Hz. are sounded together, the number of beats per second will be:

(***2011, 2009, 04 Karachi Board***)

(A) 3. (B) 4. (C) 5. (D) 6.

***Q.No.26***: The frequency of waves produced in a stretched string depends upon:

(***2012 Karachi Board***)

(A) Length. (B) Tension.

(C) Linear density. (D) All of these.

***Q.No.27***: The maximum number of beats that can be detected by the human ear is:

(***2013, 06,07 Karachi Board***)

(A) 2 (B) 3 (C) 5 (D) 7

***Q.No.28***: Two vibrating bodies having slightly different frequencies produce:

(***2016 Karachi Board***)

(A) Echo (B)Beats (C)Resonance (D)Polarization

***Q.No.29***: The velocity of a wave of wave length '$\lambda$' and frequency '$\nu$' is given by:

(***2015 Karachi Board***)

(A) $\nu / \lambda$ (B) $\lambda / . \nu$ (C) $\nu\lambda$ (D) $1/\nu\lambda$

***Q.No.30***: If the frequency of fifth harmonic of a vibrating string is 200 Hz. its fundamental frequency is: (***2017 Karachi Board***)

(A) 5 Hz. (B) 25 Hz. (C) 40 Hz. (D) 100 Hz.

***Q.No.31***: The speed of sound in vacuum is:

(***2017, 2010 Karachi Board***)

(A)zero(B)332 $ms^{-1}$(C)33200$cm\,s^{-1}$(D)$3\times10^{8}ms^{-1}$

***Q.No.32***: Intensity of sound is measured in:

(***2018 Karachi Board***)

(A)watt/$m^2$ (B)joule/m (C)watt/s (D) watt/m

***Q.No.33***: When temperature of air rises the speed of sound waves increases, because:

(***2018, 08 Karachi Board***)

(A)The frequency of waves increases.

(B)The wavelength of waves increases

(C)Both the frequency and wavelength increases

(D)Neither frequency nor wavelength increases

***Q.No.34***: Beats are produced due to:

(***2019, 08 Karachi Board***)

(A) diffraction of waves in time.

(B) reflection of waves in time.

(C) Polarization of waves in time.

(D) interference of waves in time.

***Q.No.35***: The product of frequency and time period is:(***2019 Karachi Board***)

(A) 1 (B) 2 (C) 3 (D) 4

***Q.No.36***: The range of audible sound is:

(***2022, 2016 Karachi Board***)

(A)1 Hz. to 10 Hz. (B) 20 Hz. to 20,000 Hz.

(C) 21,000 Hz. to 24,000 Hz.

(D) 25,000 Hz. and onwards.

***Q.No.37***: Pitch of sound depends upon:

(***2022 Karachi Board***)

(A) Amplitude (B) Intensity.

(C) Frequency. (D) Loudness.

***Q.No.38***: Distance between two consecutive nodes in a standing wave is:

(***2022, 2017,14, 06 Karachi Board***)

(A) $\lambda / 4$ (B) $\lambda$ (C) $\lambda /2$ (D) $\lambda /3$

***Q.No.39*: Speed of sound in air at STP is 332 m/s. If the air pressure becomes double at the same temperature, the speed of sound will become:(***2025 Karachi Board***)

(A)1382 m/s (B)664 m/s
(C) 332 m/s (D)166 m/s

***Q.No.40*:** The Doppler effect is used in this medical imaging technique.
(***2026 Karachi Board***)

(A) Ultrasound. (B) X-rays.
(C) MRI. (D) CT scan.

***Q.No.41*:** The speed of sound in air at STP is 332 m/s. If the air pressure becomes double at the same temperature then the speed of sound will be:
(***2026 Karachi Board***)

(A) 1382 m/s. (B) 332 m/s.
(C) 664 m/s. (D) 166 m/s.

## ***Answers***:

(1) (B) $\omega$ /k
(2) (A) $\pi/2$
(3) (B) $v_m > v_h > v_a$
(4) (C) 332 m/s.
(5) (A) $v \propto P^0$
(6) (B) square root of adiabatic elasticity.
(7) (B) $\frac{1}{7}$ L
(8) (A) $f_1 = f_2$ both are greater than 620Hz.
(9) (A) 338m/s
(10) (B) 25.3 m.
(11) (B) 5000 Hz.
(12) (A) Temperature.
(13) (C) Harmonics.
(14) (C) Polarization.
(15) (B) Interference.
(16) (B) sound waves.
(17) (A) solid.
(18) (B) Quality.
(19) (A) $\nu = \frac{1}{2\pi}\sqrt{g/L}$
(20) (C) $\sqrt{2}$ times.
(21) (C) 200 Hz.
(22) (C) 2 times.
(23) (A) Solids.
(24) (B) Sound waves.
(25) (B) 4.
(26) (D) All of these.
(27) (D) 7.
(28) (B) Beats.
(29) (C) $\nu\lambda$.
(30) (C) 40 Hz.
(31) (A) zero.
(32) (A) watt/$m^2$.
(33) (B) The wavelength of waves increases
(34) (D) interference of waves in time.
(35) (A) 1
(36) (B) 20 Hz. to 20,000 Hz.
(37) (C) Frequency.
(38) (C) $\lambda$ /2
(39) (C) 332 m/s.
(40) (A) Ultrasound.
(41) (B) 332 m/s.

## Numericals:

***Q.No.4***: **An increase in pressure of 100 kPa causes a certain volume of water to decrease by $5\times10^{-3}$ percent of its original volume.**
**Find: (a) Bulk modulus of water.**
**(b) What is the speed of sound in water?**

***Data***:

Increase in pressure $\Delta P = 100$ kPa
$= 100\times1000$ Pa $= 10^5$ Pa
Decrease in volume $\Delta V = 5\times10^{-3}$ % of V
(V is the original volume)

$\therefore \quad \Delta V/V = 5\times10^{-3}$ %

$\Delta V/V = \frac{5\times10^{-3}}{100} = 5\times10^{-5}$

(a) Bulk modulus of water =?
(b) Speed of sound in water v =?

***Solution***:

(a) Bulk modulus is given by:

Bulk modulus $B = \frac{\Delta P}{\Delta V/V} = \frac{10^5}{5\times10^{-5}} = 0.2\times10^5\times10^5$

Bulk modulus B = $0.2\times10^{10}$ Pa.
$= 2000\times10^6$ Pa = **2000 MPa**

(b) Speed of sound is given by:

$V = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{2000\times10^6}{10^3}} = \sqrt{2000\times10^3}$

($\rho$ is the density of water)

V = **1414 m/s.**

Bulk modulus is **2000 MPa** and the speed of sound in water is **1414 m/s**.

***Q.No.5***: **A uniform string of length 10.0 m and weighing 0.25 N is attached to the ceiling. A weight of 1.00 kN hangs from its lower end. The lower end of the string is suddenly displaced horizontally. How long does it take the resulting wave pulse to travel to upper end.**
**(Neglect the weight of string in comparison to hanging mass).**

***Data***:

Length of string L = 10.0 m.
Weight of string $W_1$ = 0.25 N.
Mass of string $m = \frac{W}{g} = \frac{0.25}{9.8} = 0.0255$ kg.
Weight suspended $W_2$= T= 1.0 kN= $10^3$ N
(T is tension in the string = weight suspended)
Time to travel to upper end t =?

***Solution***:

Distance travelled is given by:
$S = Vt$ OR $t = \frac{S}{V}$

But speed V of a wave in string is given by:

$V = \sqrt{\frac{TL}{m}} = \sqrt{\frac{10^3\times 10}{0.0255}} = 626.22$ m/s.

Hence: $t = \frac{S \text{ (or L)}}{V} = \frac{10}{626.22} = 0.015969$s

**= 15. 969 ms = 16 ms.** (ms = millisecond)

Wave pulse will take about **16 ms.** to travel to the upper end.

***Q.No.6***: **A travelling sin wave is the result of the superposition of two other sin waves with equal amplitude, wavelength and frequencies. The two component waves each have amplitude 5.00 cm. If the resultant wave has amplitude 6.69 cm.**
**What is the phase difference "φ" between the component waves?**

***Data***:

Amplitude of each wave $A_o$ = 5 cm.
Amplitude of resultant wave A= 6.69 cm
Phase difference $\varphi$ = ?

***Solution***:

Amplitude of resultant wave is given by:

$A = 2 A_o \cos(\varphi/2)$

$6.69 = 2\times5\cos(\varphi/2)$

$\frac{6.69}{10} = \cos(\varphi/2) \qquad \cos(\varphi/2) = 0.669$

$(\varphi/2) = \cos^{-1} 0.669 \qquad (\varphi/2) = 48°$

$\therefore \quad \varphi = 48\times2 = 96°$

Phase difference between the waves is **96°**

***Q.No.7***: **In order to decrease the fundamental frequency of a guitar string by 4.0 %, by what percentage should you reduce the tension?**

***Data***:

Decrease in frequency = 4% of '*f*'
(where '*f*' is the fundamental frequency)
% decrease in tension =?

***Solution*:**

Let '$f$' be the fundamental frequency, the new frequency is given by:

$f' = (100 - 4)\%$ of $f = 96\%$ of $f = 0.96\, f$

Fundamental frequency of a wave in string is given by: (M is mass per unit length)

$$f = \frac{1}{2L}\sqrt{\frac{T}{M}} \quad \ldots\ldots\ldots\ldots (i)$$

New frequency in the string is given by:

$$f' = \frac{1}{2L}\sqrt{\frac{T'}{M}} \quad \text{(M is mass per unit length)}$$

$$0.96\, f = \frac{1}{2L}\sqrt{\frac{T'}{M}} \quad \ldots\ldots\ldots\ldots (ii)$$

Dividing $(ii)$ by $(i)$ we get:

$$\frac{0.96\, f}{f} = \frac{1}{2L}\sqrt{\frac{T'}{M}} \Big/ \frac{1}{2L}\sqrt{\frac{T}{M}}$$

$$0.96 = \sqrt{\frac{T'}{T}}$$

Squaring both sides and re-arranging:

$0.9216\, T = T'$

But Percentage decrease in T $= \dfrac{\text{Decrease in T}}{T} \times 100$

Percentage decrease in T $= \dfrac{T - T'}{T} \times 100\%$

Percentage decrease in T $= \dfrac{T - 0.9216T}{T} \times 100\%$

Percentage decrease in T $= \dfrac{\cancel{T}(1 - 0.9216)}{\cancel{T}} \times 100\%$

Percentage decrease in T $= 0.0784 \times 100\% =$ **78.4%**

Percentage decrease in tension will be **78.4%**.

***Q.No.8*: A string 2.0 m long is fixed at both ends. If a sharp blow is applied to the string at its center, it takes 0.050 s for the pulse to travel to both ends of the string and return to its middle. What is the fundamental frequency of oscillation for this string?**

***Data*:**

Length of the string $L = 2$ m.
Time taken $t = 0.05$ s.
Fundamental frequency $f = ?$

***Solution*:**

When a string fixed at both ends is disturbed from its center, one loop is formed, it is said to vibrate with fundamental frequency, which is given by:

$$f = \frac{v}{2L} \qquad \text{But } v = \frac{L}{t}$$

$$f = \frac{L/t}{2L} = \frac{\cancel{L}}{2\cancel{L}t} = \frac{1}{2t} = \frac{1}{2 \times 0.05} = \mathbf{10Hz.}$$

Fundamental frequency is **10 Hz.**

***Q.No.9*: A sound source of frequency "$f_o$" and an observer are located at a fixed distance apart. Both the source and observer are at rest. However, the propagation medium (through which the sound waves travel at speed v) is moving at a uniform velocity "$v_m$" in an arbitrary direction. Find the frequency detected by the observer giving physical explanation.**

***Data*:**

Speed of sound $= v$
Speed of the medium $= v_m$.
Frequency detected when medium flows in the direction of sound waves $f_1 = ?$
Frequency detected when medium flows against the direction of sound waves $f_2 = ?$

***Solution*:**

Speed with which sound waves reach the observer depends not only upon its own speed "v" but also upon the magnitude and direction of speed "$v_m$" of the medium. Hence:

- When the source of sound and an observer are **at rest relative to each other**, frequency of sound emitted will be equal to the frequency of sound received.
- When medium flows **in the direction of sound waves** Speed with which sound waves are received by the observer will be "$v + v_m$", now the frequency of sound received is given by:

$$\boxed{f_1 = \frac{v + v_m}{\lambda}} \qquad (\text{since } f\lambda = v)$$

- When medium flows **against the direction of sound waves,** Speed with which sound waves are received by the observer will be "v – $v_m$", now the frequency of sound received is given by:

$$\boxed{f_2 = \frac{v - v_m}{\lambda}} \qquad (\text{since } f\lambda = v)$$

***Note that***: frequency of sound heard by a listener changes (*i*) due to a **change in its wave length** when the source of sound moves.

OR (*ii*) due to a **change in its speed** with which sound waves reach the listener when either the listener or the medium or both move

***Q.No.10*: A train sounds its whistle while passing by a railroad crossing. An observer at the crossing measures a frequency of 219 Hz. as the train approaches the crossing and a frequency of 184 Hz as the train leaves. The speed of sound is 340 m/s. Find the speed of the train and frequency of its whistle.**

***Data*:**

Frequency of sound heard when source **approaches** the listener $f' = 219$ Hz

Frequency of sound heard when source **moves away** from the listener $f'' = 184$ Hz

Speed of sound V = 340 m/s.

Speed of the train $V_s$ =?

Frequency of the whistle $f$ =?

***Solution*:**

Frequency of sound heard by a stationary listener when the train **approaches** him is given by:

$$f' = \frac{V}{V - V_s} \times f$$

$$219 = \frac{340}{340 - V_s} \times f$$

$$219\,(340 - V_s) = 340\,f$$

$$219 \times 340 - 219\,V_s = 340\,f \,\ldots\ldots\ldots(i)$$

Frequency of sound heard by a stationary listener when the train **moves away** from him is given by:

$$f'' = \frac{V}{V + V_s} \times f$$

$$184 = \frac{340}{340 + V_s} \times f$$

$$184\,(340 + V_s) = 340\,f$$

$$184 \times 340 + 184\,V_s = 340\,f \,\ldots\ldots\ldots(ii)$$

LHS of (*i*) and (*ii*) are equal, therefore:

$$184 \times 340 + 184\,V_s = 219 \times 340 - 219\,V_s$$

$$184\,V_s + 219\,V_s = 219 \times 340 - 184 \times 340$$

$$403\,V_s = 11900$$

$$V_s = \frac{11900}{403} = \mathbf{29.53\ m/s.}$$

Put the value of $V_s$ in equation (*ii*) we get:

$$184 \times 340 + 184 \times 29.53 = 340\,f$$

$$f = \frac{184 \times 340 + 184 \times 29.53}{340} = \mathbf{200\ Hz.}$$

🗣 Speed of the train is **29.53 m/s** and frequency of its whistle is **200 Hz**.

***Q.No.11*: A guitar string has a linear density of 7.16 g/m and under tension of 152 N. The fixed supports of the string are 89.4 cm apart. If it vibrates in three segments, calculate the speed, the wave length and the frequency of the standing wave.** (***1996 Karachi Board***)

***Data*:**

Linear density $\mu$ = 7.16 g/m $= 7.16 \times 10^{-3}$ kg./m

Tension in the string T = 152 N

Length of three segments $l$ = 89.4 cm = 0.894 m

Speed of the wave V =?

Frequency $f$ =?

Wave length $\lambda$ =?

***Solution*:**

Speed of waves in a string under tension is given by:

$$V = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{152}{7.16 \times 10^{-3}}}$$

$$V = \sqrt{21229.05} \qquad \boxed{V = 145.7\ m/s}$$

Wave length of the wave when the string vibrates in three segments is given by:

$$\lambda = \frac{2\,l}{3} = \frac{2 \times 0.894}{3} = \frac{1.788}{3}$$

$$\boxed{\lambda = 0.596\ m.}$$

Frequency with which the string vibrates is given by:

$$f = \frac{V}{\lambda} = \frac{145.7}{0.596}$$ $$\boxed{f = 244.5\ Hz.}$$

***Q.No.12*: The siren of an ambulance at rest is producing a frequency of 2000 hertz.**

**What frequency will be heard by a listener moving towards the ambulance with a velocity of 100 km/hour?**

**Velocity of sound in air=1200 km/hour.**

**(*2001 Karachi Board*)**

***Data*:**

Frequency of sound produced $f$=2000 Hz.

Frequency heard $f' = ?$

Velocity of listener $V_o$ = 100 km/h

Velocity of sound V = 1200 km/h

***Solution*:**

Frequency of sound heard by a listener approaching a stationary source is given by:

$$f' = \frac{V + V_o}{V} \times f = \frac{1200 + 100}{1200} \times 2000$$

$$f' = \frac{1300}{1200} \times 2000$$ $$\boxed{f' = 2166.7\ Hz.}$$

***Q.No.13*: Calculate the speed of sound in air at S.T.P What is the speed of sound at 37°C?**

**(Given: density of air = 1.29 Kg/m$^2$ $\gamma$ for air = 1.42, 1atm. = 1.01×10$^5$ N/m$^2$)**

**(*2002 Karachi Board*)**

***Data*:**

Speed of sound at S.T.P V= ?

Speed of sound at 37° $V_{37}$ =?

Temperature t = 37°

Density of air $\rho$ = 1.29 Kg/m$^2$

For air $\gamma$ = 1.42

1atm. = 1.01×10$^5$ N/m$^2$

***Solution*:**

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

$$V = \sqrt{\frac{1.42 \times 1.01 \times 10^5}{1.29}} = \sqrt{111178.29}$$

$$\boxed{V = 333.43\ m/s}$$

Speed of sound at any temperature t is given by

$$V_t = V\sqrt{\frac{t + 273}{273}}$$

$$V_{37} = 333.43\sqrt{\frac{37 + 273}{273}} \quad \text{(at 37°C)}$$

$$V_{37} = 333.43 \times \sqrt{1.1355}$$

$$V_{37} = 333.43 \times 1.066$$

$$\boxed{V_{37} = 355.31\ m/s}$$

Speed of sound at STP is ***333.43 m/s*** and at 37°C is ***355.31 m/s***.

***Q.No.14*: Two cars are moving straight to each other from opposite directions with the same speed. The horn of one is blowing with the frequency of 3000 Hz. and is heard by people in the other car with the frequency of 3400 Hz.**

**Find the speed of the car if speed of sound in air is 340 m/s.**

**(*2003 Karachi Board*)**

***Data*:**

Frequency produced $f$ = 3000 Hz

Frequency heard $f'$=3400 Hz.

Speed of sound V = 340 m/s

Speed of each car $V_o = V_S$ =?

***Solution*:**

Since both the cars, one producing sound (source) and in the other there is a listener, are moving opposite to each other. Hence frequency of sound heard is given by:

$$f' = \frac{V + V_o}{V - V_S} \times f$$

Both cars are approaching each other with same speed, therefore, $V_s = V_o$

$$3400 = \frac{340 + V_o}{340 - V_o} \times 3000$$

$$3400\,(340 - V_o) = (340 + V_o)\,3000$$

$$3400 \times 340 - 3400\,V_o = 3000 \times 340 + 3000\,V_o$$

$$3400 \times 340 - 3000 \times 340 = 3400 \times V_o + 3000\,V_o$$

$$1156000 - 1020000 = 6400\,V_o$$

$$136000 = 6400\,V_o$$

$$V_o = \frac{136000}{6400}$$

$$\boxed{V_o = 21.25\ m/s}$$

Speed of each car is ***21.25 m/s***.

**<u>*Q.No.15*</u>: A standing wave is established in a 2.4 m long string fixed at both ends. The string vibrates in four segments (loops) when driven at 200 Hz Determine:**

**(1) The wave length.**

**(2) The fundamental frequency.**

**(*2018, 2004, 1994 Karachi Board*)**

**<u>*Data*</u>:**

Length of the string $L = 2.4$ m
Number of segments $n = 4$
Frequency $f_4 = 200$ Hz.
Wave length $\lambda_4 = ?$
Fundamental frequency $f_1 = ?$

**<u>*Solution*</u>:**

Wave length of the wave is given by:

$$\lambda_n = \frac{2L}{n}$$

$$\lambda_4 = \frac{2 \times 2.4}{4} \qquad \boldsymbol{\lambda_4 = 1.2\ m}$$

🗣wave length of standing waves when the string vibrates in four segments is ***<u>1.2 m</u>***.

Similarly: $f_1 = \frac{f_4}{4}$ $\left\{ f_1 = \frac{f_n}{n} \right\}$

$$f_1 = \frac{200}{4} \qquad \boxed{f_1 = 50Hz}$$

Fundamental frequency is ***<u>50Hz</u>***.

**<u>*Q.No.16*</u>: A note of frequency 650 Hz. Is emitted from an ambulance. What frequency will be detected by a listener if the ambulance moves**

**(*i*) at speed of 18 m/s. <u>towards</u> the listener.**

**(*ii*) at speed of 15 m/s <u>away</u> from the listener**

**(Speed of sound = 340 m/s).**

**(*2008 Karachi Board*)**

**<u>*Data*</u>:**

Frequency of sound $f = 650$ Hz.
Frequency of sound detected $f' = ?$
(*i*) Speed of ambulance
$V_s = 18$ m/s (<u>towards</u>)
(*ii*) Speed of ambulance
$V_s = 15$ m/s (<u>away</u>)
Speed of sound $V = 340$ m/s.

**<u>*Solution*</u>:**

Frequency of sound detected by a stationary listener when a source of sound moves ***towards him*** is given by:

$$f' = \frac{V}{V - V_s} \times f$$

$$\therefore \quad f' = \frac{340}{340 - 18} \times 650$$

$$\therefore \quad f' = \frac{340}{322} \times 650 \qquad \boxed{f' = 686.3\ Hz.}$$

🗣Frequency of sound heard by the listener when the ambulance ***<u>moves towards him</u>*** is ***<u>686.3 Hz</u>***.

Frequency of sound detected by a stationary listener when ambulance moves ***away from him*** is given by:

$$f' = \frac{V}{V + V_s} \times f$$

$$\therefore \quad f' = \frac{340}{340 + 15} \times 650$$

$$\therefore \quad f' = \frac{340}{355} \times 650 \qquad \boxed{f' = 622.54\ Hz.}$$

🗣Frequency of sound heard by the listener when the ambulance ***<u>moves away from him</u>*** is ***<u>622.54 Hz</u>***.

**<u>*Q.No.17*</u>: A note of frequency of 500 Hz. Is being emitted by an ambulance moving towards a listener at rest. If the listener detects a frequency of 526 Hz.**

**Calculate the speed of ambulance. (Speed of sound is 340 m/s at that moment)**

**(*2011, 2009, 05, 07 Karachi Board*)**

**<u>*Data*</u>:**

Frequency emitted $f = 500$ Hz.
Frequency detected $f' = 526$ Hz.
Speed of sound $V = 340$ m/s.
Speed of ambulance $V_s = ?$

**<u>*Solution*</u>:**

When the ambulance approaches a stationary listener with speed $V_s$, frequency of sound heard by the listener is given by:

$$f' = \frac{V}{V - V_s} f$$

$\therefore \quad 526 = \frac{340}{340 - V_s} \times 500$

$\therefore \quad 340 - V_s = \frac{340 \times 500}{526}$

$\therefore \quad 340 - V_s = 323.194$

$\therefore \quad V_s = 340 - 323.194 \quad \boxed{V_s = 16.8\ m/s}$

Ambulance is approaching the listener with a speed of ***16.8 m/s***.

***Q.No.18*: Find the speed of sound in a gas when two waves of wave lengths 0.80 m and 0.81 m respectively, produce four beats per sec.** (***2012, 1992 Karachi Board***)

***Data*:**

Wave length of first wave $\lambda_1 = 0.80$ m

Wave length of second wave $\lambda_2 = 0.81$ m

Number of beats per second n = 4

speed of sound V =?

***Solution*:**

If "$f_1$" and "$f_2$" are the frequencies of the two waves, then:

$f_1 = \frac{V}{\lambda_1} \quad \& \quad f_2 = \frac{V}{\lambda_2}$

But the number of beats heard per second is equal to the difference of frequencies of the two waves:

$\therefore$ Number beats per second $= f_1 - f_2$

$\therefore$ Number beats per second $= \frac{V}{\lambda_1} - \frac{V}{\lambda_2}$

$\therefore$ Number beats per second $= V\left\{\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right\}$

$\therefore \quad 4 = V\left\{\frac{1}{0.80} - \frac{1}{0.81}\right\}$

$4 = V\,(1.25 - 1.23457)$

$4 = 0.01543\ V$

$V = \frac{4}{0.01543} \quad \boxed{V = 259.24\ m/s.}$

speed of sound in the gas is ***259.24m/s.***

***Q.No.19*: A sound wave of frequency 500 Hz. in air enters a region of temperature 25°C to a region of temperature 5°C. Calculate the percentage fractional change in wave length.**

(***2013 Karachi Board***)

***Data*:**

Frequency of sound $f = 500$ Hz.

Initial temperature $T_1 = 25°C$

$= 25 + 273 = 298$ k

Final temperature $T_2 = 5°C$

$= 5 + 273 = 278$ k

Percentage fractional change in wave length $\frac{\Delta\lambda}{\lambda_1}\% = ?$

***Solution*:**

Let speed of sound in air at $T_0 = 0°C$ or 273 k be $V_0 = 332$ m/s, therefore, speed of sound at $T_1$ can be calculated by:

$\frac{V_1}{V_0} = \sqrt{\frac{T_1}{T_0}}$ OR $\frac{V_1}{332} = \sqrt{\frac{298}{273}}$

$\frac{V_1}{332} = \sqrt{1.0916} = 1.045$

Therefore: $V_1 = 1.045 \times 332$

$\boldsymbol{V_1 = 346.87\ m/s}$

Hence wavelength '$\lambda_1$' of waves at temperature '$T_1$' will be:

$\lambda_1 = \frac{V_1}{f} = \frac{346.87}{500} = \boldsymbol{0.694\ m}$

Similarly, speed at $T_2$ is given by:

$\frac{V_2}{V_0} = \sqrt{\frac{T_2}{T_0}}$

$\frac{V_2}{332} = \sqrt{\frac{278}{273}}$

$\frac{V_2}{332} = \sqrt{1.018} = 1.0091$

$\therefore \quad V_2 = 1.0091 \times 332$ or $\boldsymbol{V_2 = 335.027 m/s}$

Hence wavelength '$\lambda_2$' of waves at temperature '$T_2$' will be:

$\lambda_2 = \frac{V_2}{f} = \frac{335.027}{500} = \boldsymbol{0.670\ m}$

Fractional change in wave length (or change in wavelength per unit wave length) is given by $\frac{\Delta\lambda}{\lambda_1} = \frac{\lambda_1 - \lambda_2}{\lambda_1}$

$\frac{\Delta\lambda}{\lambda_1} = \frac{0.694 - 0.670}{0.694} = 0.03458$

$\therefore$ Percentage fractional change in wave length = fractional change × 100%

🗣Percentage fractional change in wave length = 0.03458×100%=***3.458 %.***

***Q.No.20*: A car has a siren sounding a 2 kHz. tone . What frequency will be detected by a stationary observer as the car approaches him at 80 km./h?**

**Speed of sound = 1200 km./h**

(***2015, 2015, 1998 Karachi Board***)

***Data*:**

Frequency of sound produced by the siren $f$ =2 kHz.= 2000 Hz.

Speed of the car (source) $V_S$ = 80 km./h

Speed of sound $V$ = 1200 km./h

Frequency of sound heard by the listener $f'$ =?

***Solution*:**

In this case a source of sound (car) approaches a stationary listener (observer), hence the frequency of sound detected by the observer will be:

$$f' = \frac{V}{V - V_S} \times f$$

$$f' = \frac{1200 \times 2000}{1120} = \frac{2400000}{112}$$

$\boxed{f' = 2142.9\ Hz}$ OR $\boxed{f' = 2.143\ kHz.}$

🗣Frequency of sound heard by the listener is ***2.143 kHz.***

***Q.No.21*: A source of sound and a listener are moving towards each other with velocities which are 0.5 time and 0.2 time the speed of sound respectively. If the source of sound is emitting 2 kilo-Hertz tone, calculate the frequency heard by the listener.**

(***2022, 1995,93 Karachi Board***)

***Data*:**

Speed of source of sound $V_S$ = 0.5 V

Speed of listener $V_O$ = 0.2 V

Frequency of sound emitted $f$ =2 kHz.= 2000Hz

Frequency of sound heard by listener $f'$ =?

***Solution*:**

In this case source of sound and the listener both approach each other, therefore, frequency of sound heard by the listener is given by:

$$f' = \frac{V + V_O}{V - V_S} \times f$$

$$f' = \frac{V + 0.2\ V}{V - 0.5\ V} \times f$$

$$f' = \frac{1.2\ V}{0.5\ V} \times f$$

$$f' = \frac{1.2}{0.5} \times f = 2.4 \times f = 2.4 \times 2000$$

$\boxed{f' = 4800\ Hz.}$ $\boxed{f' = 4.8\ kHz.}$

🗣Frequency of sound heard when source of sound and the listener move towards each other is ***4800 Hz.*** OR ***4.8 kHz.*** It is more than the sound emitted, therefore, sound heard is more shrill.

***Q.No.22*: A car has been sounding 4 kHz tone. What frequency will be detected by a stationary listener as the car approaches him at 50 km./h.**

**(Speed of sound in air = 1200 km./h).** (***2025 Karachi Board***)

***Data*:**

Speed of the car $V_S$ = 50 km./h.

Speed of sound in air $V$ = 1200 km./h

Frequency of sound emitted $f$ =4 kHz. = 4000Hz

Frequency of sound heard by listener $f'$ =?

***Solution*:**

In this case a source of sound (car) approaches a stationary listener (observer), hence the frequency of sound detected by the observer will be:

$$f' = \frac{V}{V - V_S} \times f$$

$$f' = \frac{1200 \times 4000}{1200 - 50}$$

$$f' = \frac{4800000}{1150}$$

$\boxed{f' = 4174\ Hz.}$ OR $\boxed{f' = 4.174\ kHz.}$

🗣Frequency of sound heard by the listener is ***4.174 kHz.***

***Q.No.23*: If speed of sound in air at 27°C is 345 m/s, find its speed at 47°C.**

(***2026 Karachi Board***)

***Data***:

Speed of at 27°C $V_1$= 345 m/s.
Temperature $T_1$ = 27°C.
= 27+ 273 = 300 k.
Speed of at 47°C $V_2$=?
Temperature $T_2$ = 47°C.
= 47+ 273 = 320 k.

***Solution***:

Speed of sound at two different temperatures $T_1$ and $T_2$ is related by:

$$\frac{V_2}{V_1} = \sqrt{\frac{T_2}{T_1}}$$

$$\frac{V_2}{345} = \sqrt{\frac{320}{300}}$$

$$\frac{V_2}{345} = \sqrt{1.0667} = 1.0328$$

∴ $V_2$ =1.0328×345 or ***$V_2$=356.314m/s***

🗣Speed of sound at 47°C is ***356.314m/s***.

***Q.No.24*: A 4 m long string fixed at both ends vibrates in two loops with a frequency of 20 Hz. Find the speed of the traveling waves. (*2026 Karachi Board*)**

***Data***:

Length of the string L = 4 m.
Number of loops n = 2
Frequency $f$ = 20 Hz.
Speed of waves v =?

***Solution***:

Since the string fixed at both ends vibrate in two loops, therefore its wave length will be

$\lambda$ = 2 L = 2 × 4 = 8 m.

But speed of waves is given by:

v = $\lambda$ $f$ = 8 × 20 = **160 m/s.**

🗣Speed of waves is **160 m/s.**