Sound waves

Nature and propagation

Sound is produced in a material medium by a vibrating source.

Sound waves constitute alternate compression and rarefaction pulses traveling in the medium.

Sound is audible only if the frequency of alternation of pressure is between 20 Hz to 20,000 Hz.

Displacement wave and Pressure Wave

A longitudinal wave in a fluid can be described either in terms of the longitudinal displacement suffered by the particles of the medium or in terms of the excess pressure generated due to the compression or rarefaction.

Speed of a sound wave

$v = \sqrt{B/\rho}$

where

v = velocity

B = Bulk modulus of the material.

ρ = normal density of the fluid

Hence the velocity of a longitudinal wave in a medium depends on its elastic properties and inertial properties of the medium.

Newton's formula for speed of sound in a gas

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

The density of air at temperature 0°C and pressure 76 cm of mercury column is $\rho = 1.293 \text{ kg/m}^3$

So $P = .76\text{m} * (13.6*10^3 \text{ kg/ m}^3) * (9.8 \text{ m/s}^2) = 101292.8$

Hence $P/\rho = 78339.37$

$\sqrt{P/\rho} = 279.8917$ m/s

The velocity of sound in air comes as 280 m/s.

But the measured value of speed of sound in air is 332 m/s

Laplace's correction

Laplace suggested a correction. With Laplace's correction the formula is

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

where $\gamma = C_p/C_v$ (C_p and C_v are molar heat capacities at constant pressure and constant volume respectively)

With this new formula the value comes out to be 331.1723 closer to 332 m/s.

Effect of pressure, temperature and humidity on speed of a sound wave

The speed of sound is not affected by the change in pressure provided the temperature is kept constant. If pressure is changed but the temperature is kept constant, the density varies proportionately and P/ρ remains constant.

Speed of sound increases with increasing humidity. The density of water vapour is less than dry air at the same pressure. Thus, the density of moist air is less than that of dry air.

Intensity of sound waves

The intensity of a sound wave is defined as the average energy crossing a unit cross sectional area perpendicular to the direction of propagation of the wave in unit time.

The loudness of sound that we feel is mainly related to the intensity of sound. It also depends on the frequency to some extent.

Appearance of sound to human ear

The appearance of sound to human ear is characterised by three parameters.

1. pitch

2. loudness

3. quality

1. Pitch: Higher the frequency, higher will be the pitch.

2. Loudness: Loudness that we sense is related to the intensity of sound though it is not proportional to it.

3. A sound generated by a source contains a number of frequency components in it. Certain sounds have well defined frequencies which have considerable amplitude. Such sounds are particularly pleasant to the ear.

Interference of sound waves

Resultant change in pressure due to superposition of two sound waves.

$p_1 = p0_1 \sin(kx - \omega t)$

$p_2 = p0_2 \sin[k(x + \Delta x) - \omega t]$

$= p0_2 \sin\{(kx - \omega t) + \delta]$

Where $\delta = k\Delta x = 2\pi \Delta x / \lambda$

$P = p0\sin[(kx - \omega t) + \varepsilon]$

where

$p0^2 = p01^2 + p02^2 + 2\, p01\, p02 \cos\delta$

$\tan\varepsilon = p02 \sin\delta / (p01 + p02\cos\delta)$

the resultant amplitude is maximum when $\delta = 2n\pi$ and is minimum when $\delta = (2n+1)\pi$.

Hence when $\delta = 2n\pi$ there is constructive interference

When $\delta = (2n+1)\pi$ there is destructive interference.

Beats

The phenomenon of periodic variation of intensity of sound when two sound waves of slightly different frequencies interfere, is called beats.

Bending of waves from an obstacle or an opening is called diffraction.

Diffraction effects are appreciable when the dimensions of openings or the obstacles are comparable or smaller than the wave length of the wave.

Doppler effect

If the source of sound or the observer or both, move with respect to the medium, the frequency observed may be different from the frequency of the source. This apparent change in frequency of the wave due to motion of the source or the observer is called Doppler effect.

Mach number

Mach Number = μ_s/v

μs = speed of source creating the sound wave

v = velocity of sound wave