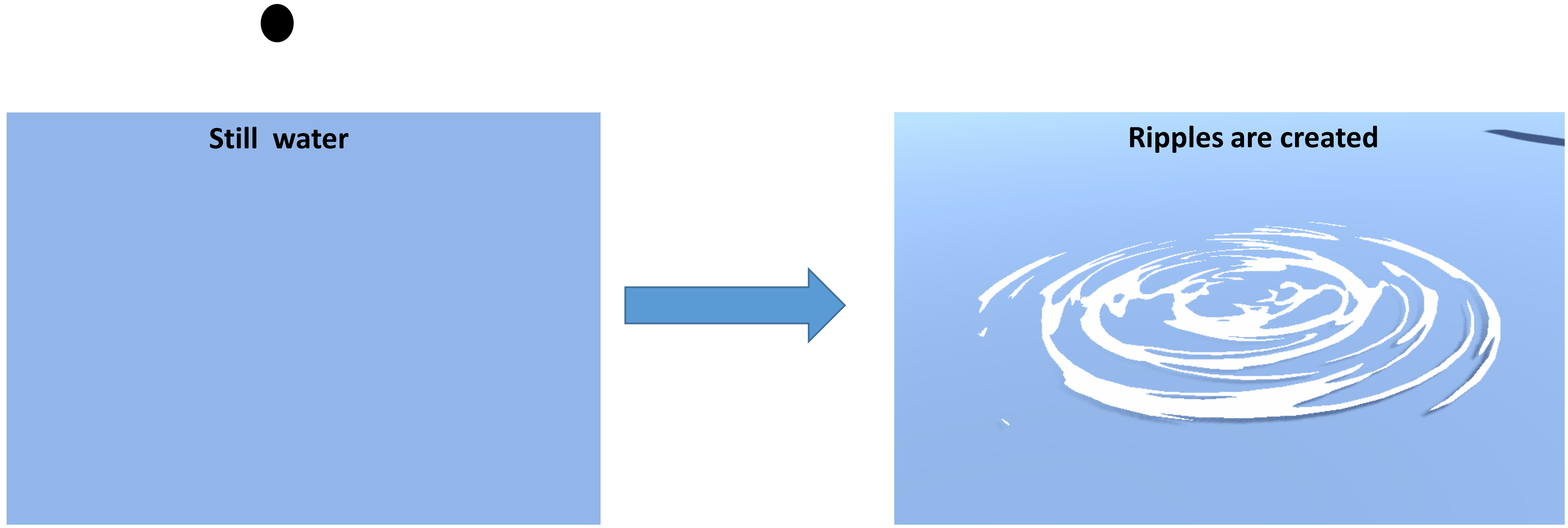
Chapter 8. SOUND

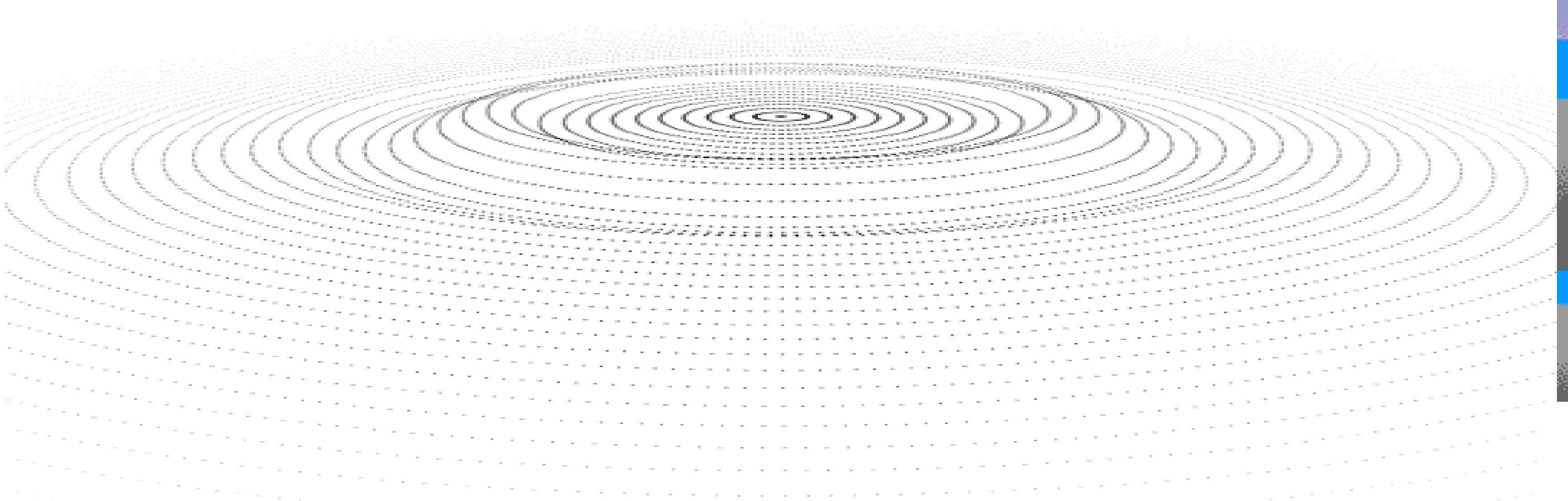
8.1 Introduction

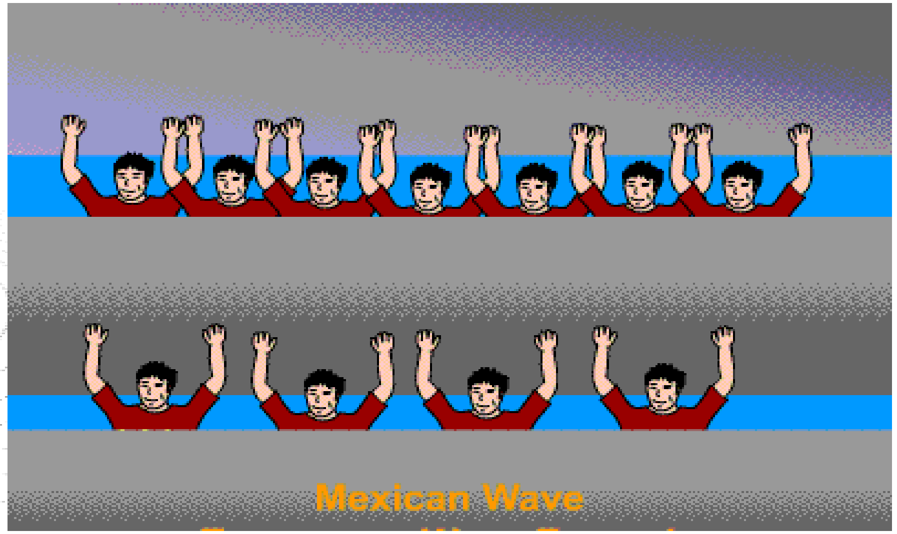


8.1 Introduction

Any motion which repeats itself after a definite interval of time is called periodic

This type of wave is **periodic** and regular disturbance in a medium which does not cause any flow of material but causes flow of energy from one point to another.





Prof. Ashwini Gonsalves

Types of waves

1. **Mechanical waves**
2. **EM waves**
3. **Matter waves**
4. **Progressive waves**

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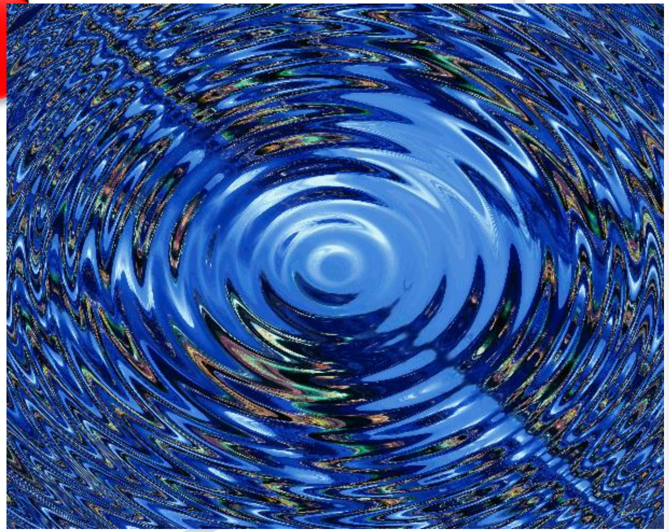
Types of waves

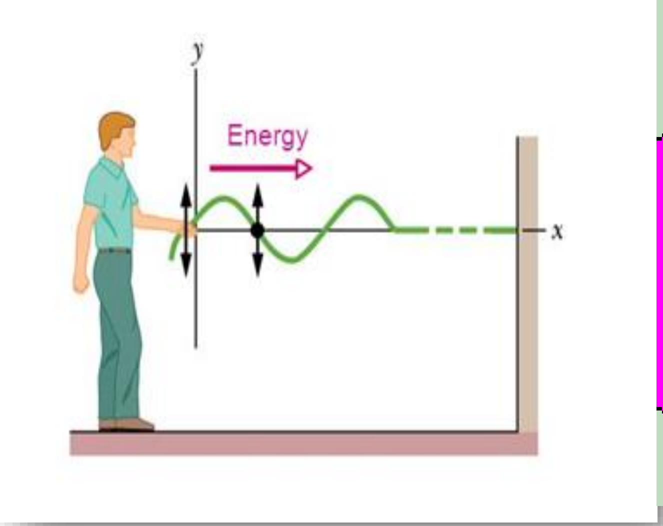
1 **Mechanical waves**

A wave is said to be mechanical wave if a material medium is essential for its propagation. E.g. water waves, waves along stretched string, sound waves, seismic waves.

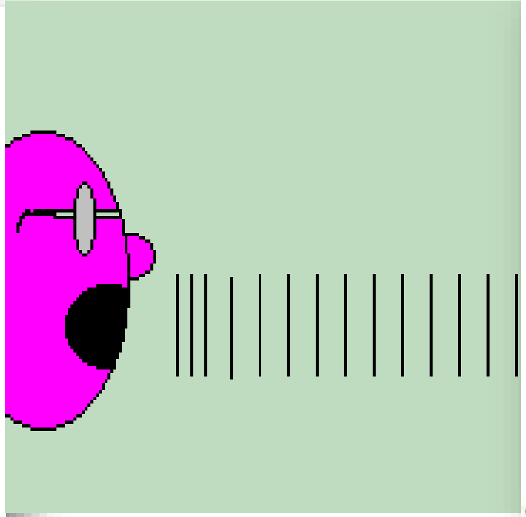
Example 1: Water waves,

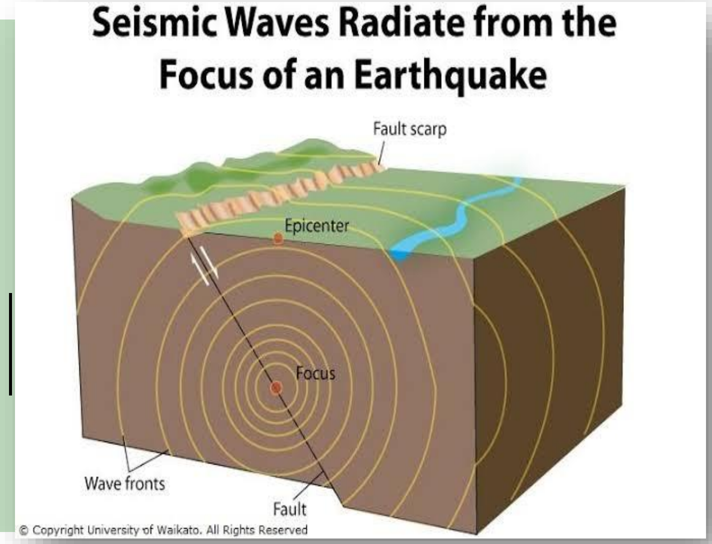


Example 2: waves along stretched string,



Example 3: Sound wave





Prof. Ashwini Gonsalves

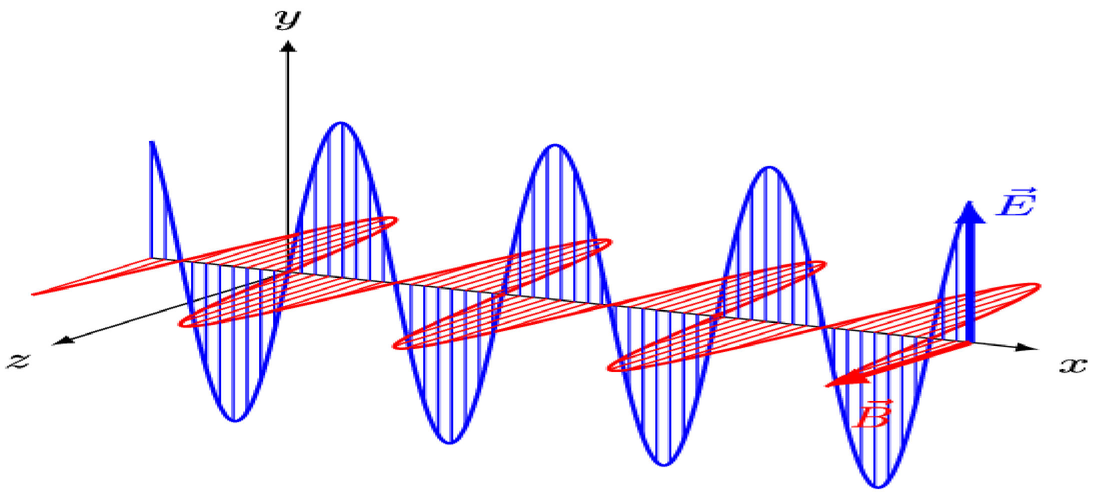
Types of waves

1 **Mechanical waves**

A wave is said to be mechanical wave if a material medium is essential for its propagation.

2 **EM waves**

These are generated due to periodic vibrations in electric and magnetic fields.



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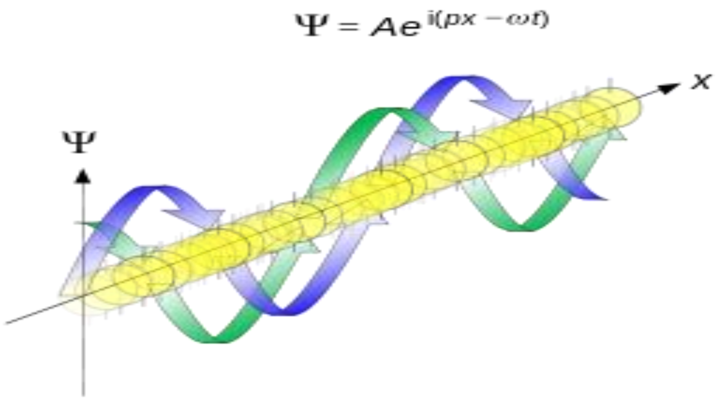
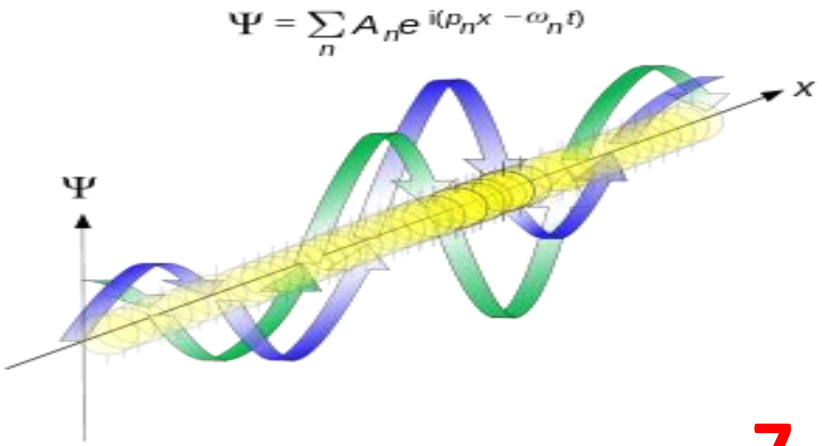


3 **Matter waves**

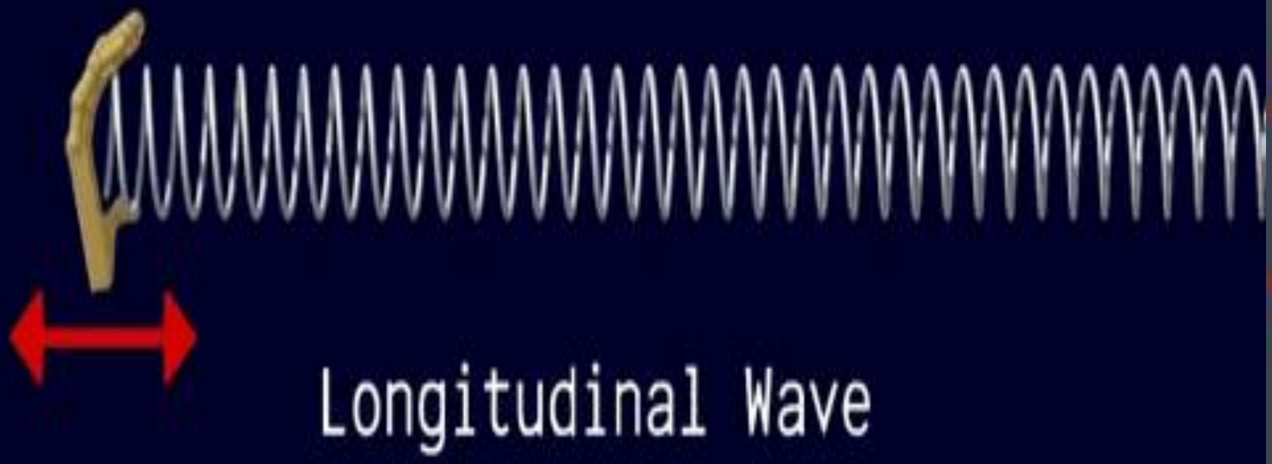
A wave which is associated with any object if it is in motion is known as matter wave.

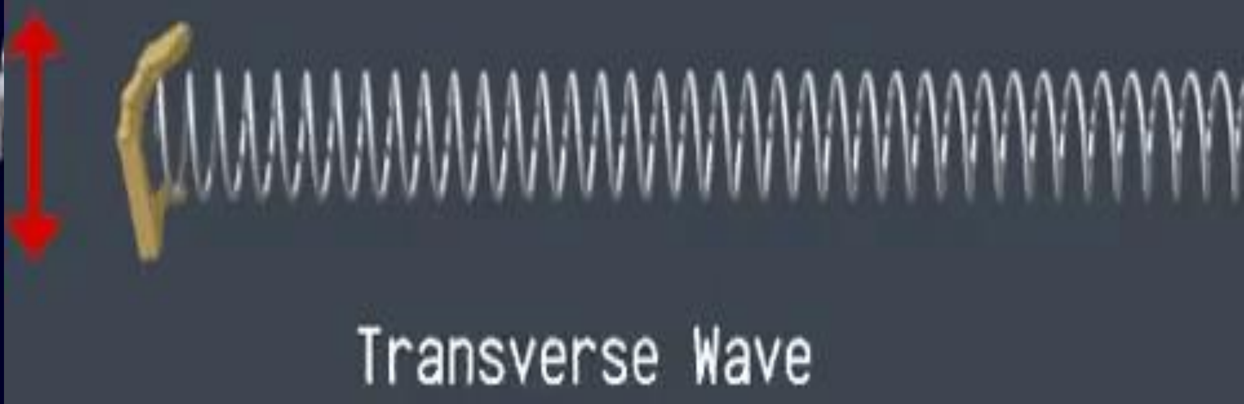


Types of waves

1. **Mechanical waves** — A wave is said to be mechanical wave if a material medium is essential for its propagation.
2. **EM waves** — These are generated due to periodic vibrations in electric and magnetic fields.
3. **Matter waves** — A wave which is associated with any object if it is in motion is known as matter wave.
4. **Progressive waves** — These are waves in which a disturbance created at one place travels to distant points and keeps travelling unless stopped by some external agencies. It is also known as Travelling wave.

Progressive waves are of two types - longitudinal waves and transverse waves





A wave in which particles of the medium vibrate in a direction parallel to the direction of propagation of wave is called Longitudinal wave.

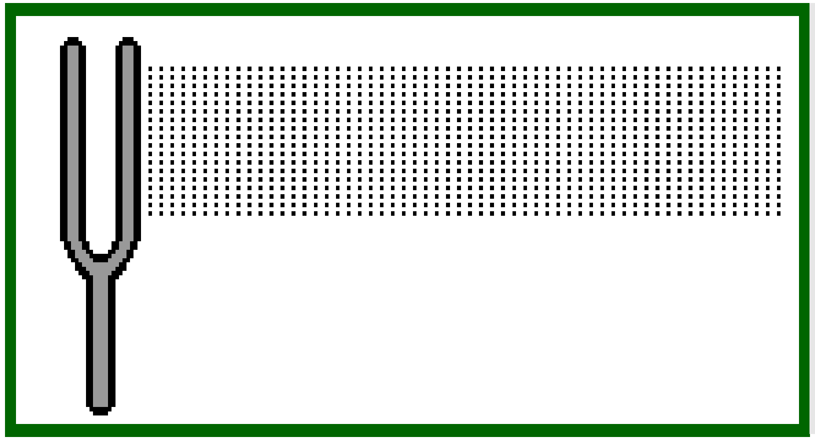
A wave in which particles of the medium vibrate in a direction perpendicular to the direction of propagation of wave is called Longitudinal wave.

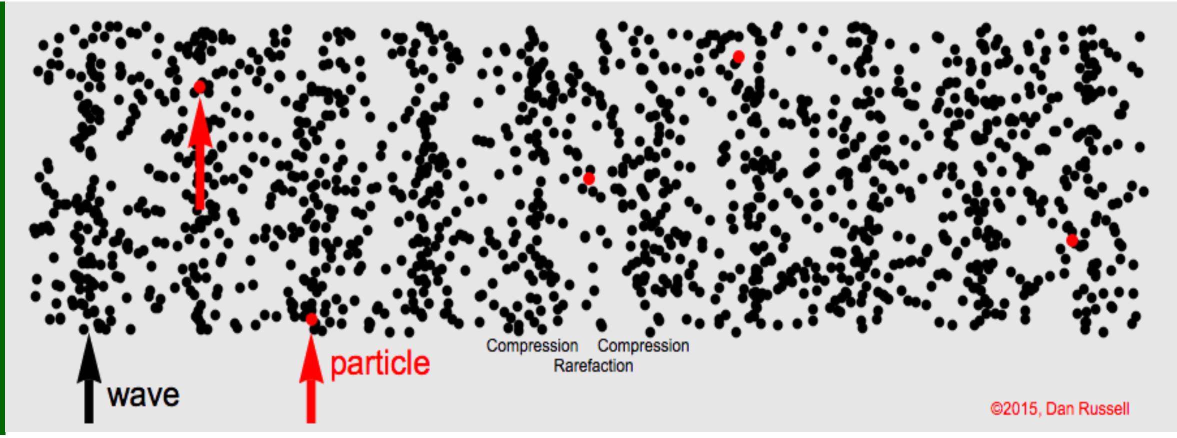
Longitudinal waves

A wave in which particles of the medium vibrate in a direction parallel to the direction of propagation of wave is called Longitudinal wave.

Example 1

Example 2

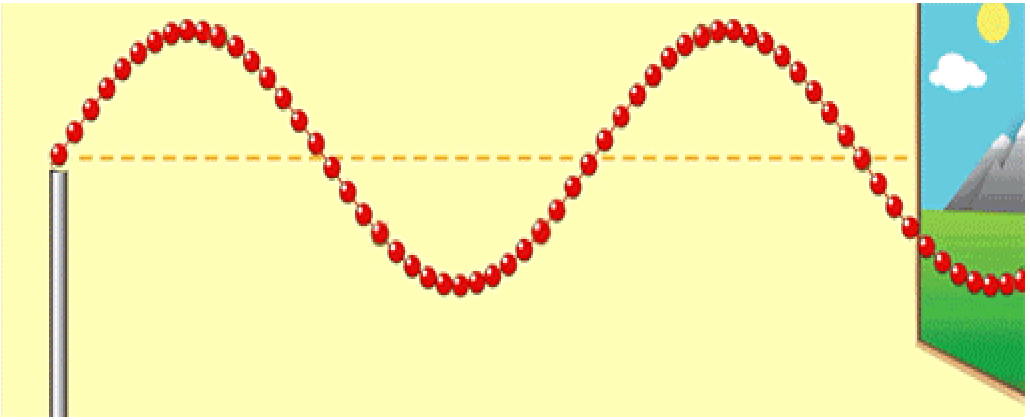




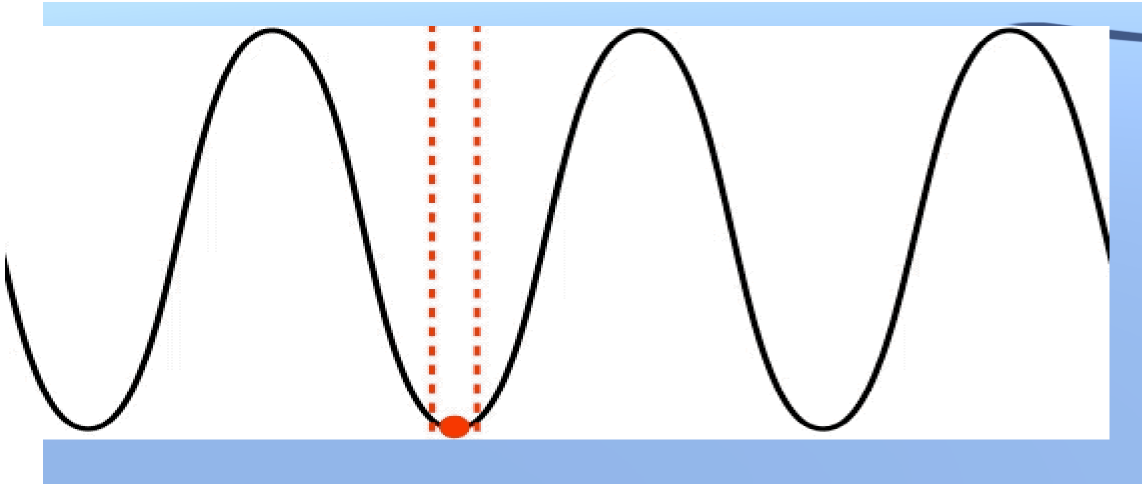
Transverse waves

A wave in which particles of the medium vibrate in a direction perpendicular to the direction of propagation of wave is called Longitudinal wave.

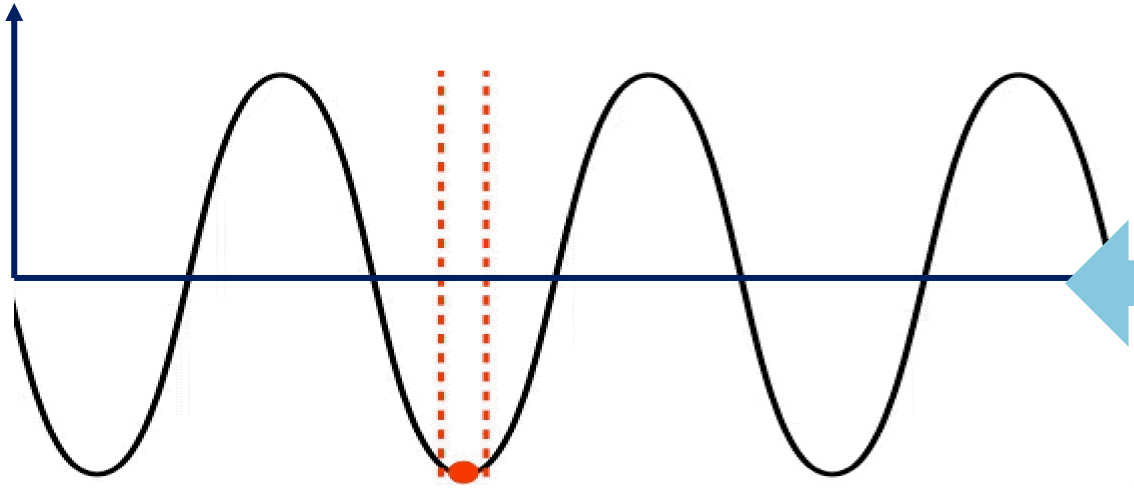
Example 1



Example 2



8.4 Mathematical Expression of a Wave



This wave can be represented by following equation:

$$y\,(x,t) = a \sin\,(kx - \omega t + \phi) \qquad \text{--- (8.4)}$$

Let us assume that the progressive wave is transverse wave.

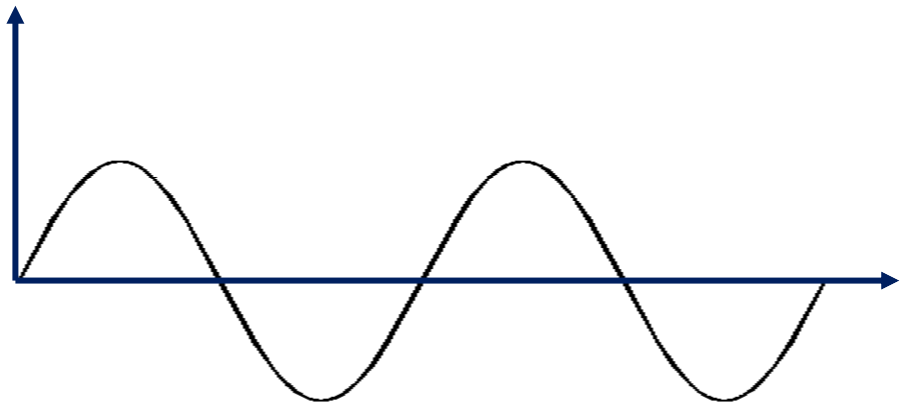
The position of the particle of the medium is described by a fixed value of x.

The displacement from the equilibrium position can be described by y.

where a, k, ω and φ are constants

a is the amplitude of the wave.
ω is the angular frequency of the wave
k is the angular wave number and
φ is phase difference

8.4 Mathematical Expression of a Wave



$$y\,(x,t) = a \sin(kx - \omega t + \phi) \qquad \text{--- (8.4)}$$

where a, k, ω and φ are constants

At a particular instant say $t = t_o$.

$$y\,(x, t_0) = a \sin(kx - \omega t_0 + \phi)$$
$$= a \sin(kx + \text{constant})$$

Thus the shape of the wave at $t = t_0$, as a function of x is a sine wave.

Also, at a fixed location $x = x_0$,

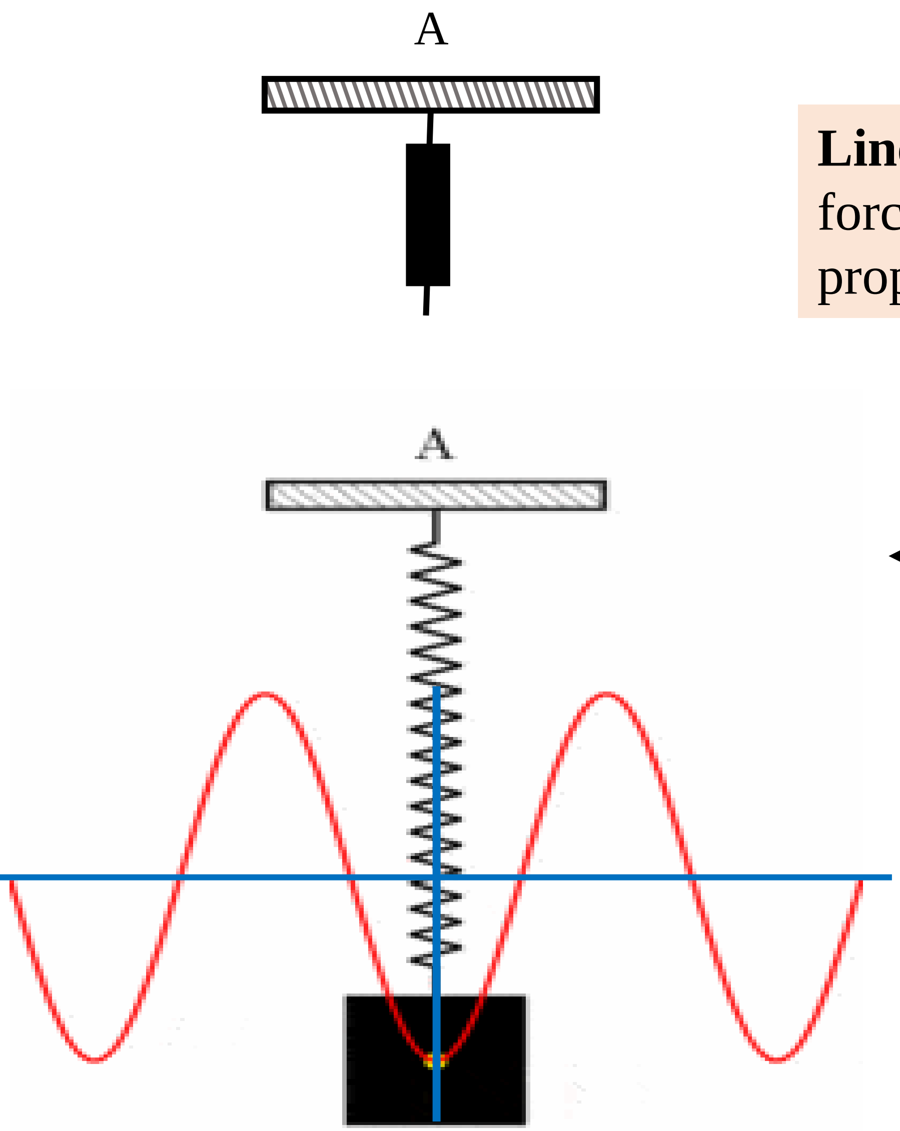
$$y\,(x_0, t) = a \sin(kx_0 - \omega t + \phi)$$
$$= a \sin(\text{constant} - \omega t)$$

Hence the displacement y, at $x = x_0$ varies as a sine function.

In addition x must increase in the positive direction as time t increases, so as to keep (kx-ωt + φ) a constant.

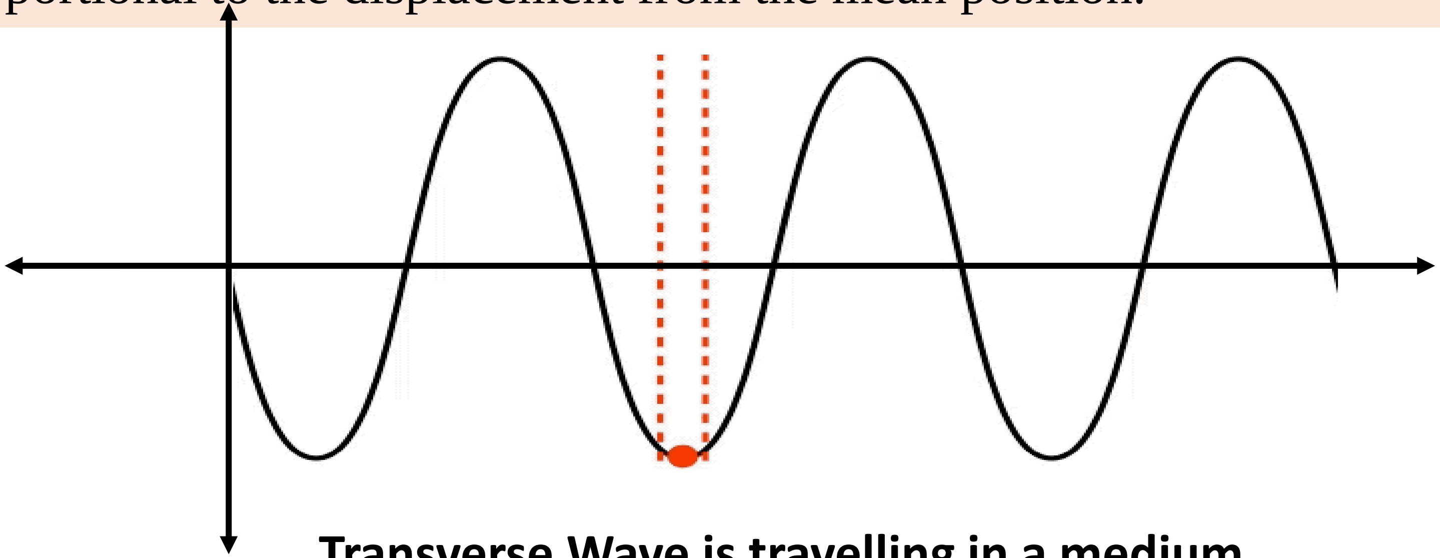
This means that the particles of the medium, through which the wave travels, execute linear simple harmonic motion around their equilibrium position.

8.4 Mathematical Expression of a Wave



Linear SIMLE HARMONIC MOTION

Linear S.H.M. is defined as the linear periodic motion of a body , in which force is always directed towards the mean position and its magnitude is proportional to the displacement from the mean position.



Transverse Wave is travelling in a medium

This means that the particles of the medium, through which the wave travels, execute **linear simple harmonic motion around their equilibrium position.**

8.4 Mathematical Expression of a Wave

$$y\,(x,t) = a \sin\,(kx - \omega t + \phi) \qquad \text{--- (8.4)}$$

where a, k, ω and φ are constants

a is the amplitude of the wave.
ω is the angular frequency of the wave
k is the angular wave number and
φ is phase difference

Thus the Eq. (8.4) represents a wave travelling along the positive x axis.

A wave represented by

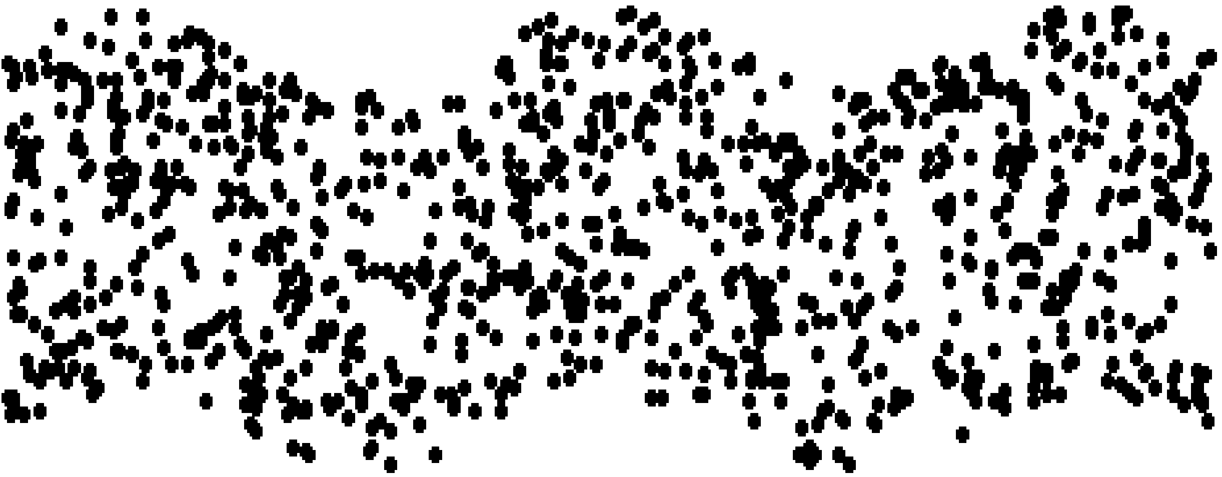
$$y(x,\,t) = a \sin\,(kx + \omega t + \phi) \qquad \text{--- (8.5)}$$

is a wave travelling in the direction of the negative x axis.

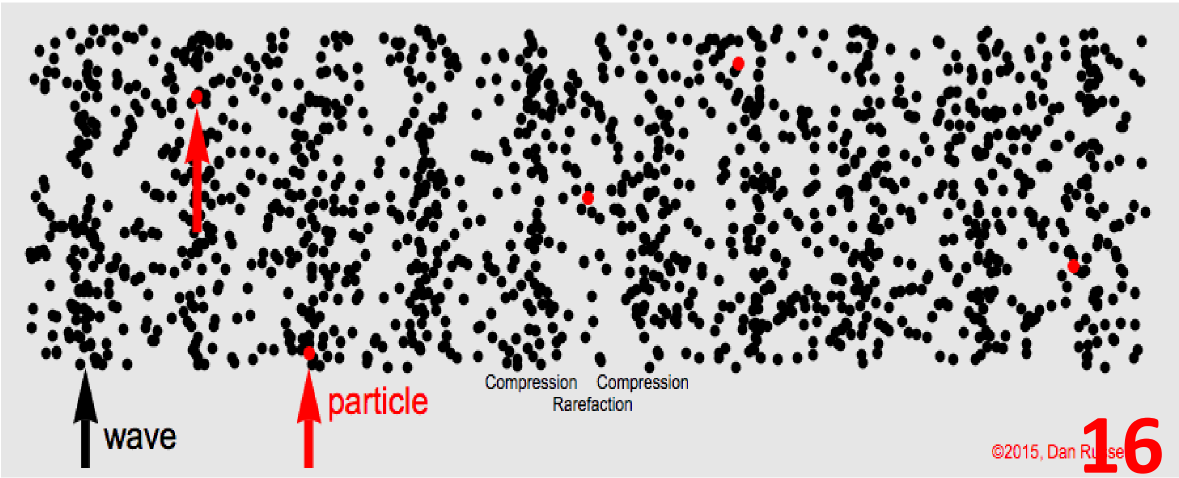
8.5 Speed of Travelling waves

- Depends upon the **elastic properties** and **density of the medium.**
- The same medium can support both transverse and longitudinal waves which **have different speeds**.

8.5.1 Speed of transverse waves



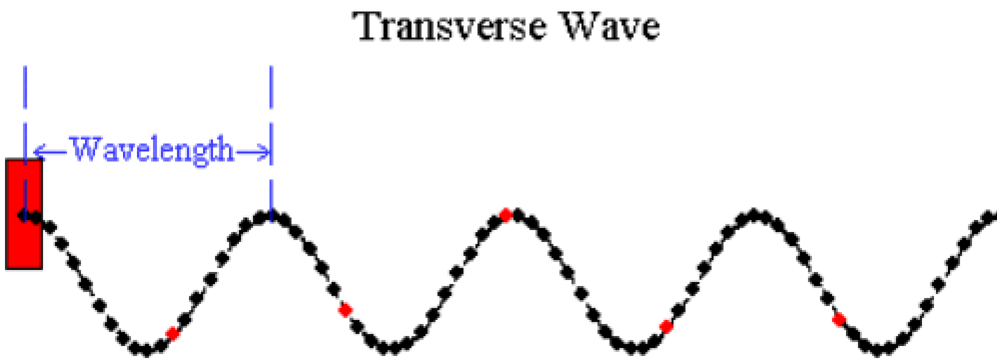
8.5.2 Speed of longitudinal waves



8.5.1 Speed of transverse waves

- The wave produced on a string are transverse wave.
- In this case the restoring force is provided by the tension T in the string.
- The linear mass density m, m = M/L.
- The formula for speed of transverse wave on stretched string is given by

$$v = \sqrt{\frac{T}{m}} \qquad \text{--- (8.6)}$$



is

Important Point:

The speed of a transverse wave depends only on the properties of the string, T and m. It does not depend on wavelength or frequency of the wave.

8.5.2 Speed of longitudinal waves

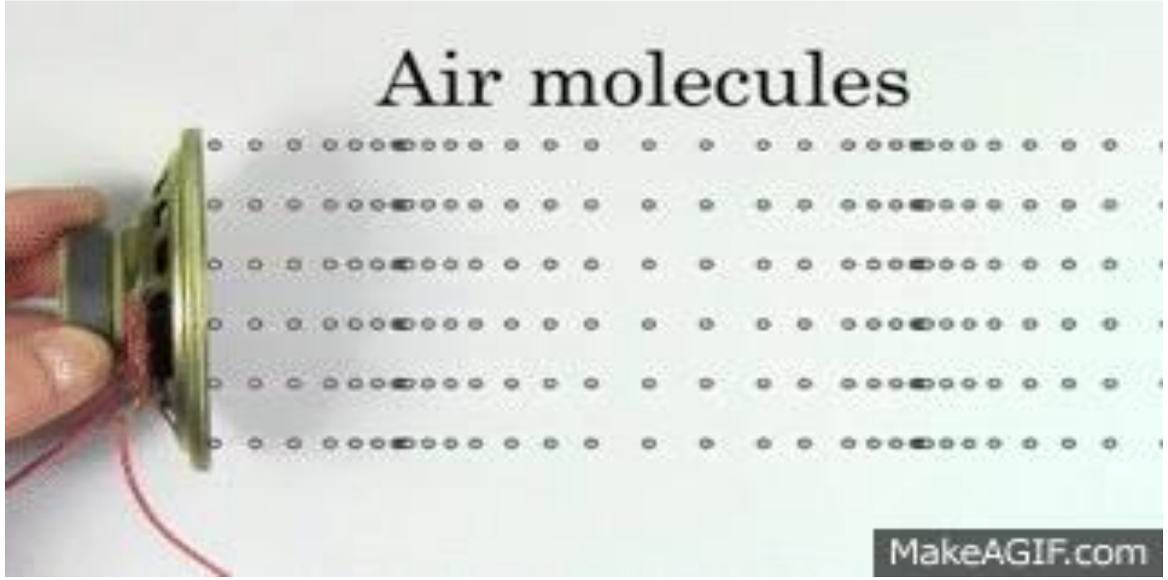


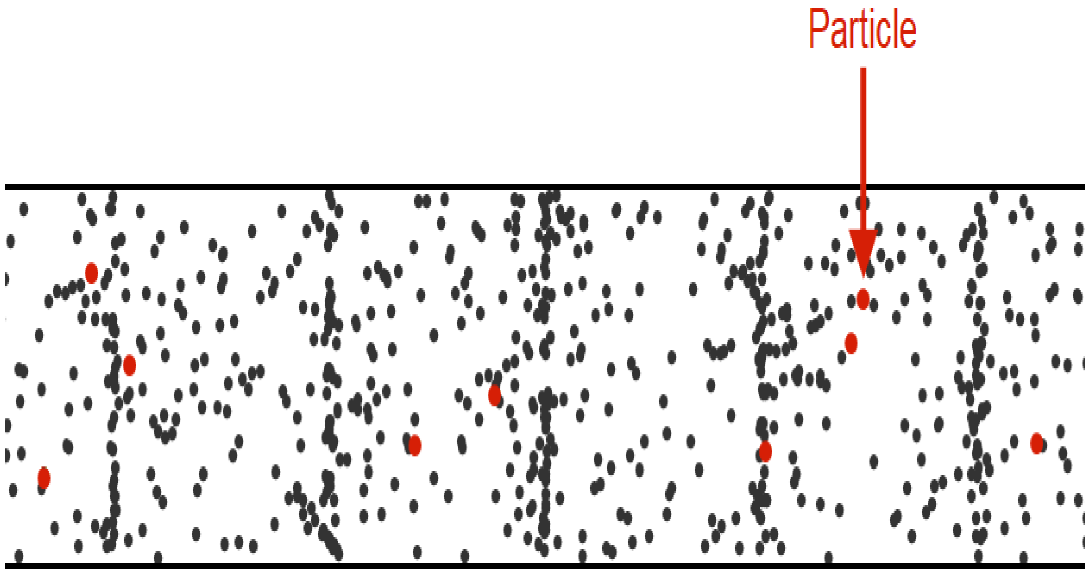
Table 8.1: Speed of Sound in Gas, Liquids, and Solids

Medium	Speed (m/s)
Gases	
Air [0°C]	331
Air [20°C]	343
Helium	965
Hydrogen	1284
Liquids	
Water (0°C)	1402
Water (20°C)	1482
Seawater	1522
Solids	
Vulcanised Rubber	54
Copper	3560
Steel	5941
Granite	6000
Aluminium	6420

Important Point:

Speed of sound in liquids and solids is higher than that in gases.

8.5.3 Newton's formula for velocity of sound



- The density of medium is greater at the compression while being smaller in the rarefaction.
- Hence the velocity of sound depends on elasticity and density of the medium.

Newton formulated the relation as

$$v = \sqrt{\frac{E}{\rho}} \qquad \text{--- (8.7)}$$

Where E is the proper modulus of elasticity of medium and ρ is the density of medium.

Newton assumed that, sound wave propagation in air is an **isothermal process**

$$v = \sqrt{\frac{P}{\rho}} \qquad \text{--- (8.8)}$$

8.5.3 Newton’s formula for velocity of sound

As atmospheric pressure is given by P=hdg

and at NTP,

$h = 0.76$ m of Hg

$d = 13600\ kg/m^3$-density of mercury

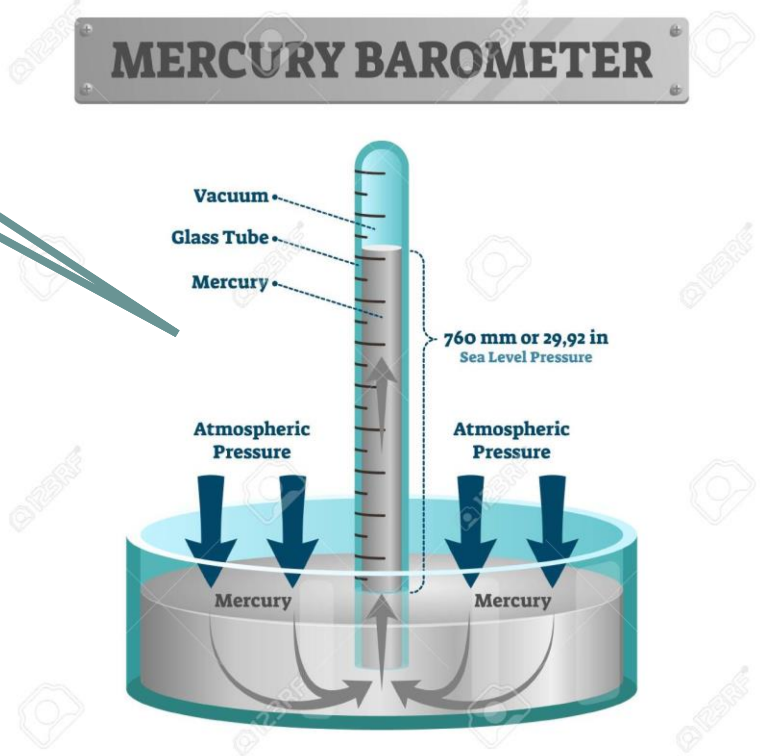
$\rho = 1.293\ kg/m^3$- density of air

$g = 9.8\ m/s^2$

$$v = \sqrt{\frac{P}{\rho}} \quad \text{--- (8.8)}$$

After substituting values in above equation we get,

$$v = \sqrt{\frac{0.76 \times 13600 \times 9.8}{1.293}}$$



sound

a.

velocity of

a number of

Newton’s Formula for speed of sound in air and its drawback

- V= $\sqrt{\frac{E}{\rho}} = \sqrt{\frac{P}{\rho}}$
- **Isothermal Process**
- At NTP v = 279.9m/s from formula , but experimental value is 332 m/s, there is a 16% discrepancy, hence Newton’s formula is not accepted.

8.5.4. Laplace's Correction to Newton's Formula

Newton's Formula

1. Generation of compression and rarefaction is a slow process.
2. Newton assumed that, sound wave propagation in air is an isothermal process.
3. Elasticity is isothermal elasticity.

Laplace's Correction

1. Generation of compression and rarefaction is a rapid process
2. Sound wave propagation in air is an adiabatic process
3. Elasticity must be adiabatic and not isothermal elasticity,

8.5.4. Laplace’s Correction to Newton’s Formula

The adiabatic modulus of elasticity of air is given by,

$$E = \gamma P \qquad \text{--- (8.9)}$$

where P is the pressure of the medium (air) and γ is ratio of specific heat of air at constant pressure (C_p) to the specific heat of air at constant volume (C_v) called as the adiabatic ratio

$$\text{i.e.,}\ \gamma = \frac{C_p}{C_v} \qquad \text{--- (8.10)}$$

For air the ratio of C_p / C_v is 1.41

$$\text{i.e.}\ \gamma = 1.41$$

Newton's formula for speed of sound in air as modified by Laplace to give

$$v = \sqrt{\frac{\gamma P}{\rho}} \qquad \text{--- (8.11)}$$

Acciriding to this formula velocity of sound at NTP is

$$v = \sqrt{\frac{1.41 \times 0.76 \times 13600 \times 9.8}{1.293}}$$

$$= 332.3 \text{ m/s}$$

This value is in close agreement with the experimental value. As seen above, the velocity of sound depends on the properties of the medium.

8.5.5 Factors affecting speed of sound

- a) Effect of pressure on velocity of sound
- b) Effect of temperature on speed of sound
- c) Effect of humidity on speed of sound

a) Effect of pressure on velocity of sound

According to Laplace's formula velocity of sound in air is

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

If M is the mass and V is volume of air then

$$\rho = \frac{M}{V}$$

$$\therefore v = \sqrt{\frac{\gamma PV}{M}} \qquad \text{--- (8.12)}$$

At constant temperature PV = constant according to Boyle's law. Also M and γ are constant, hence v = constant.

$$PV = nRT$$

$$\therefore v = \sqrt{\frac{\gamma nRT}{M}} \qquad \text{--- (8.13)}$$

Therefore at constant temperature, a change in pressure has no effect on velocity of sound in air.

change in pressure has no effect on velocity of sound unless there is change in temperature.

b) Effect of temperature on speed of sound

Suppose v_o and v are the speeds of sound at T_0 and T in kelvin respectively. Let ρ_0 and ρ be the densities of gas at these two temperatures. The velocity of sound at temperature T_0 and T can be written by using Eq. (8.13),

$$\therefore v = \sqrt{\frac{\gamma nRT}{M}} \qquad \text{--- (8.13)}$$

$$v_0 = \sqrt{\frac{\gamma RT_0}{M}}$$ --- M is molar mass, n = 1

$$v = \sqrt{\frac{\gamma RT}{M}}$$

$$\therefore \frac{v}{v_0} = \sqrt{\frac{RT}{RT_0}}$$

$$\therefore \frac{v}{v_0} = \sqrt{\frac{T}{T_0}} \qquad \text{--- (8.14)}$$

This equation shows that speed of sound in air is directly proportional to the square root of absolute temperature.

Thus, speed of sound in air increases with increase in temperature. Taking T_o = 273 K and writing T= (273 + t) K where t is the temperature in degree Celsius

The ratio of velocity of sound in air at t ^oC to that at 0 ^oC is given by,

$$\therefore \frac{v}{v_0} = \sqrt{\frac{273+t}{273}} \qquad \therefore \frac{v}{v_0} = \sqrt{1+\frac{t}{273}}$$

b) Effect of temperature on speed of sound

$$\therefore \frac{v}{v_0} = \sqrt{1+\frac{t}{273}}$$

$$\therefore \frac{v}{v_0} = \sqrt{1+\alpha t} \quad \text{where } \alpha = \frac{1}{273}$$

$$\text{or,} \quad v = v_0 (1+\alpha t)^{\frac{1}{2}}$$

As α is very small,we can write

$$v \simeq v_0 \left(1+\frac{1}{2}\alpha t\right)$$

$$v = v_0 \left(1+\frac{1}{2}\times\frac{1}{273}t\right)$$

$$v = v_0 \left(1+\frac{t}{546}\right)$$

$$v = v_0 + \frac{v_0}{546}t$$

But v_0 =332 m/s at 0^0C

$$\therefore v = v_0 + \frac{332}{546}t$$

$$\therefore v \simeq v_0 + (0.61)t, \qquad \text{--- (8.15)}$$

i.e., for 1°C rise in temperature velocity increases by 0.61 m/s.

c) Effect of humidity on speed of sound

Humidity (moisture) in air depends upon the presence of water vapour in it.

Let ρ_m and ρ_d be the densities of moist and dry air respectively.

If v_m and v_d are the speeds of sound in moist air and dry air then using Eq. (8.11).

$$v_m = \sqrt{\frac{\gamma P}{\rho_m}}$$

$$\text{and} \quad v_d = \sqrt{\frac{\gamma P}{\rho_d}}$$

$$\therefore \frac{v_m}{v_d} = \sqrt{\frac{\rho_d}{\rho_m}} \qquad \text{--- (8.16)}$$

Moist air is always less dense than dry air, i.e.,

$$\rho_m < \rho_d$$

($\rho_m = 0.81$ kg/m^3(at 0°C) and
$\rho_d = 1.29$ kg/m^3(at 0°C))

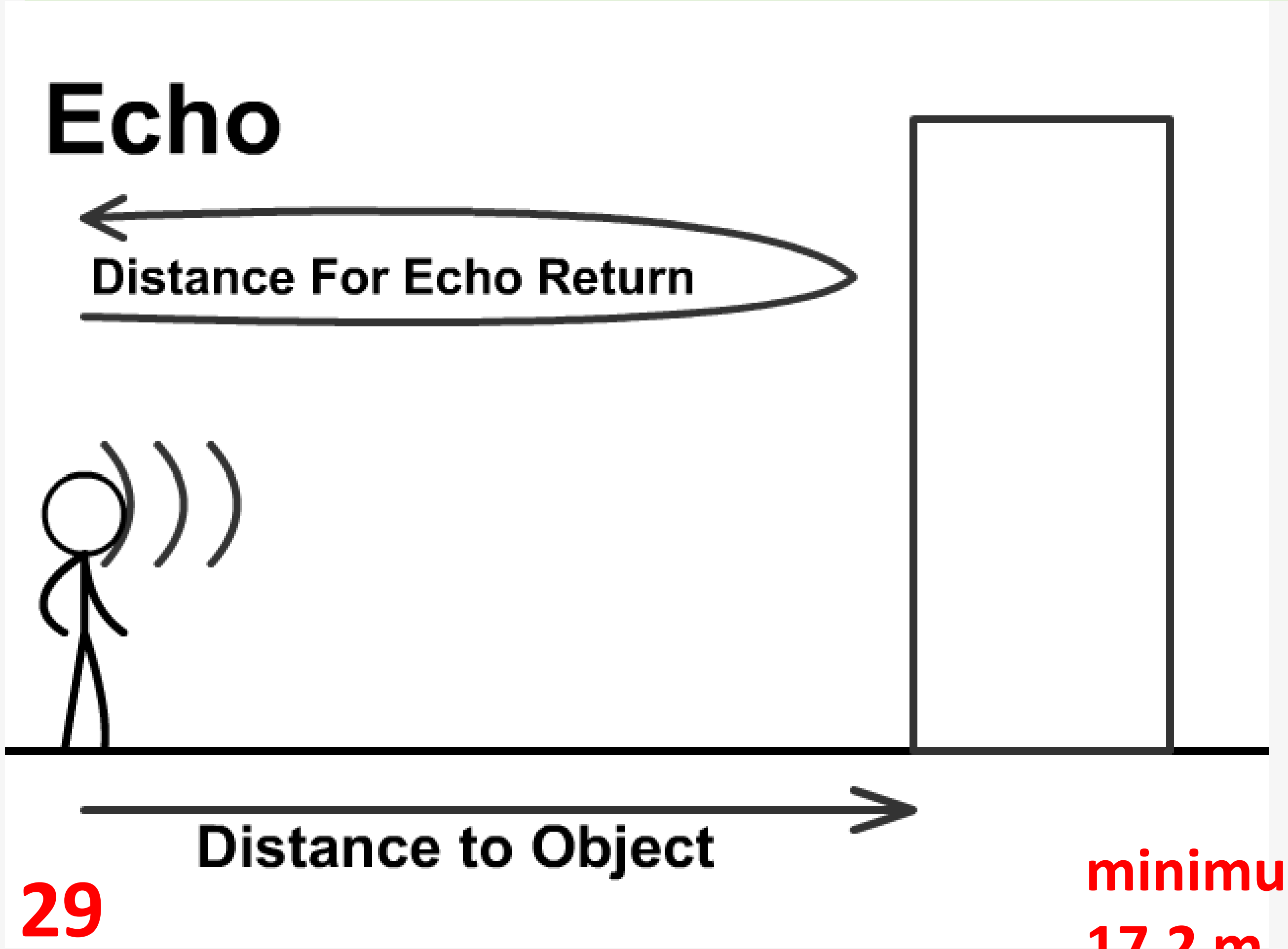
$$\therefore v_m > v_d.$$

Thus, the speed of sound in moist air is greater than speed of sound in dry air. i.e speed increases with increase in the moistness of air.

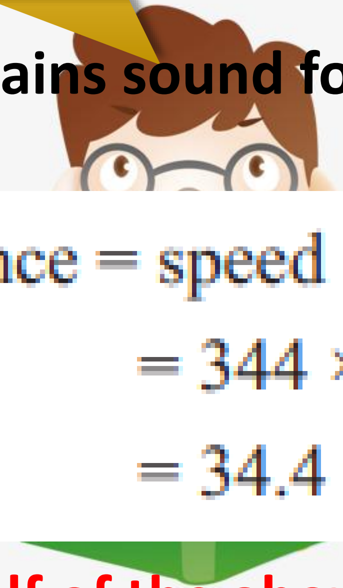
8.7 Echo, ~~reverberation~~ and ~~acoustics~~

8.7.1 Echo

An echo is the repetition of the original sound because of reflection from some rigid surface at a distance from the source of sound.



Can we hear an echo at every place?



Our brain retains sound for 0.1 second.

$$\begin{aligned} \text{distance} &= \text{speed} \times \text{time} \\ &= 344 \times 0.1 \\ &= 34.4 \text{ m.} \end{aligned}$$

minimum distance of half of the above distance i.e 17.2 m

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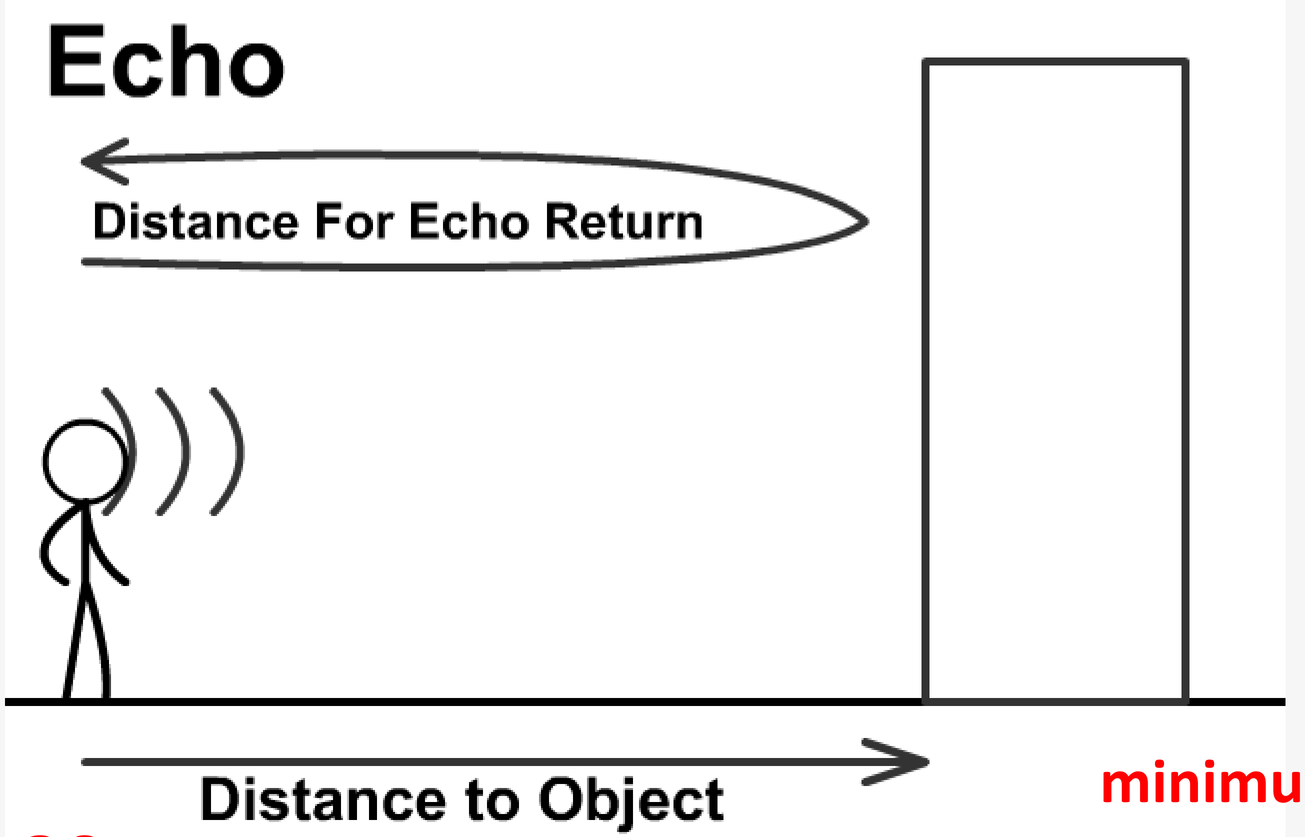

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8.8 Qualities of sound

(i) PITCH

(ii) TIMBRE

(iii) LOUDNESS

8.8 Qualities of sound

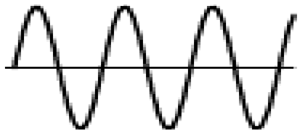
(i) PITCH

This refers to sharpness or shrillness of the sound. It is related to **the frequency** of speech. If the frequency of sound is increased , what we perceive is increase in pitch.

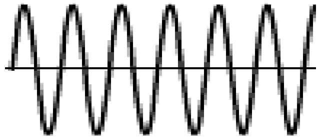
A) Tone: It refers to the single frequency of that wave.

B)Note: It may contain one or more tones.

Examples: Sound of a tabla is sharper than that of a dagga; female sound is sharper than a male sound.



Lower Pitch



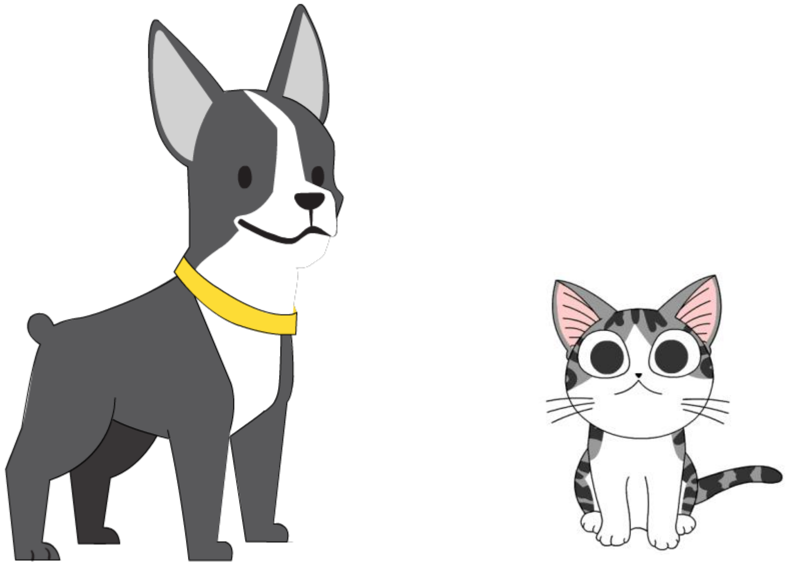
Higher Pitch

TIMBER

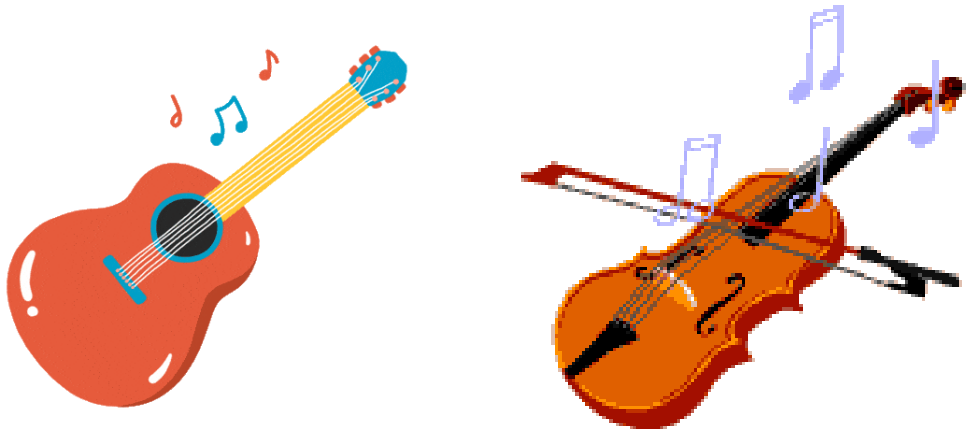

BASSOON
PIANO
CHIMES
DOUBLE BASS
MARIMBA
SAXOPHONE
FLUTE
TROMBONE
CELLO
SNARE DRUM
TRUMPET
VIOLIN
VIOLA
ELECTRIC GUITAR
OBOE
DJEMBE
CLARINET
GUITAR
BANJO
FRENCH HORN

8.8 Qualities of sound

(ii) TIMBRE



- In music, timbre (pronounced TAM-ber) describes the quality or character of a of sound or voice
- It is referred to as tone colour or tone quality.



- Timbre helps your ears distinguish one type of sound production from another. E.g.the sound of your cat from your dog.

- Timbre also helps us to differentiate instruments, even when they are playing the same pitch at the same volume.

8.8 Qualities of sound

(iii) LOUDNESS

- Intensity of a wave is a measurable quantity which is proportional to square of the amplitude (I $\propto A^2$) and is measured in the (SI) unit of W/ m^2
- **Loudness:** Human perception of intensity of sound is loudness.

I = Intensity of sound and 'd' is the distance between the source of sound and the observer.

$$I \propto \frac{1}{d^2}$$

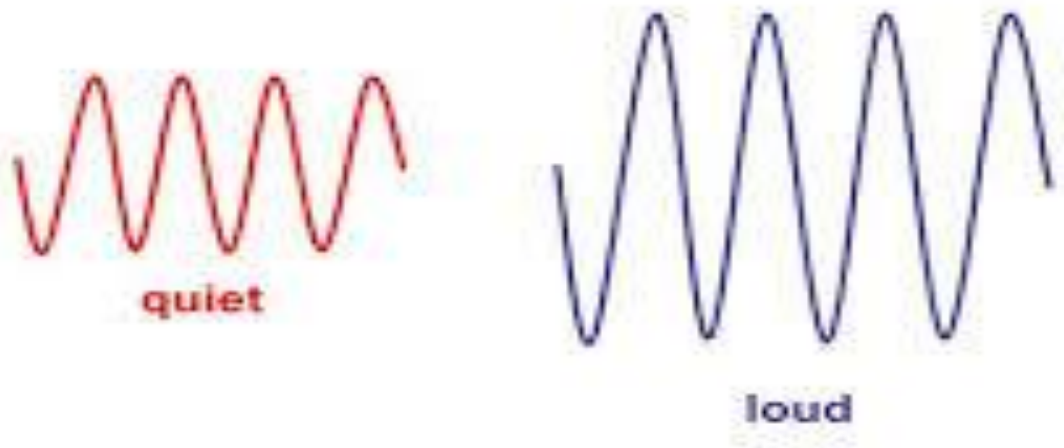
Note: When you are using earphones or jam your mobile at your ear , the distance from the source is too small. Doing this for a long time can affect your normal hearing.

8.8 Qualities of sound

(ii) LOUDNESS

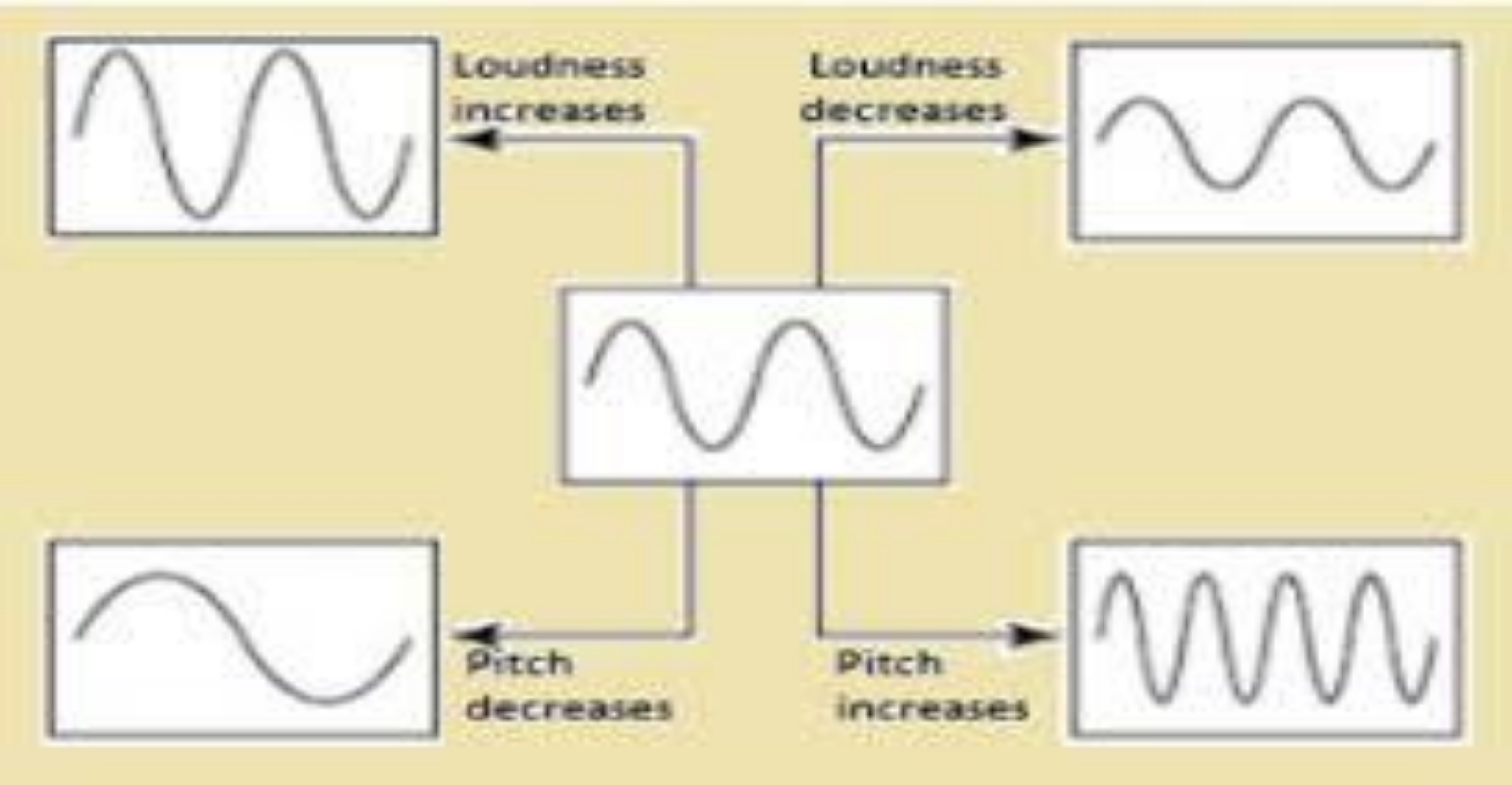
Loudness

The loudness of a sound increases with the amplitude of the sound wave.

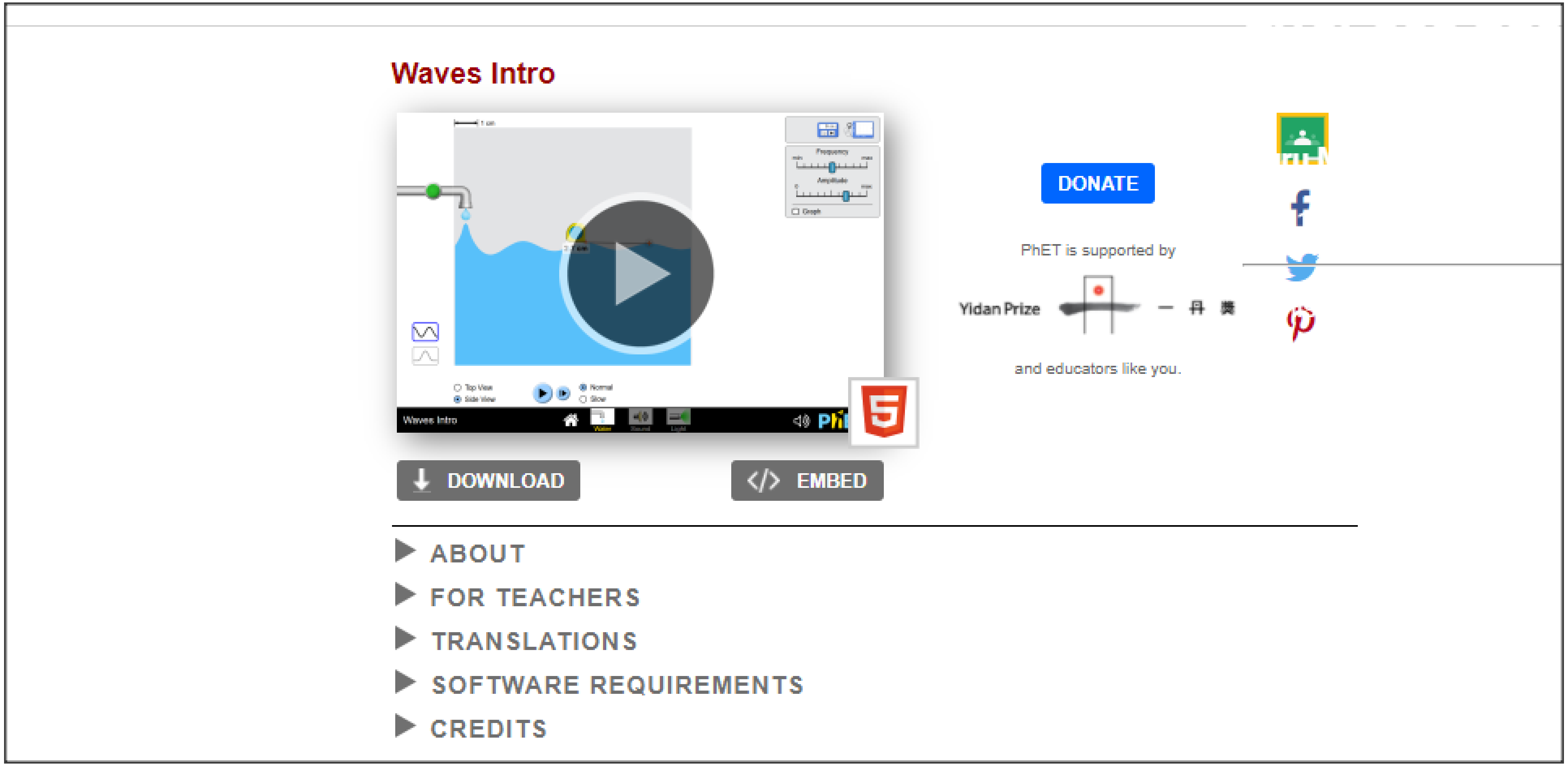


8.8 Qualities of sound

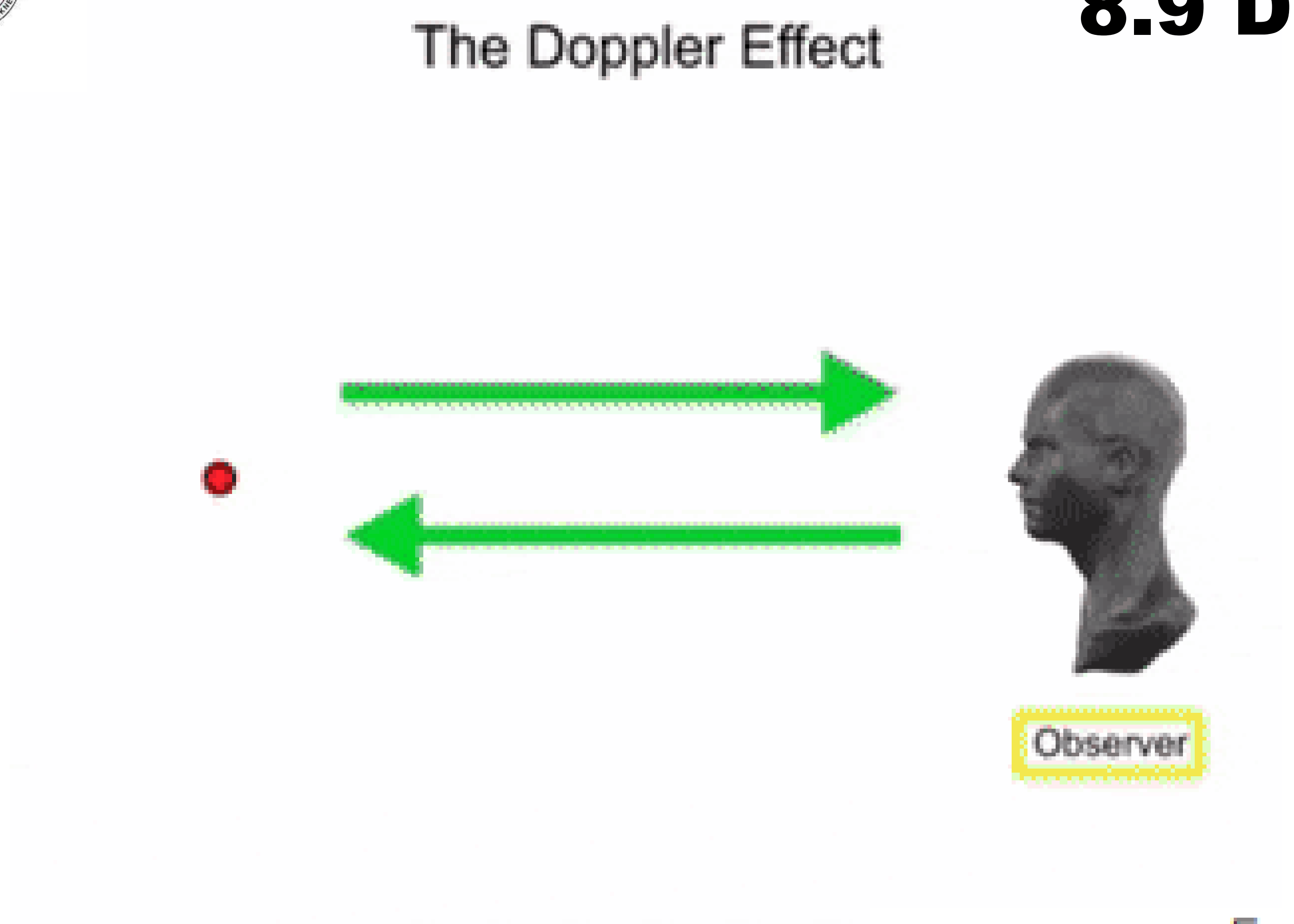
(ii) LOUDNESS



https://phet.colorado.edu/sims/html/waves-intro/latest/waves-intro_en.html



8.9 Doppler Effect



- When a source of sound and a listener are in motion relative to each other the frequency of sound heard by the listener is not the same as the frequency emitted by the source.
- Doppler effect is the apparent change in frequency of sound due to relative motion between the source and the listener.

$$n = n_0\left[\frac{v \pm v_L}{v \mp v_s}\right] \quad \text{--- (8.24)}$$

8.9 Doppler Effect

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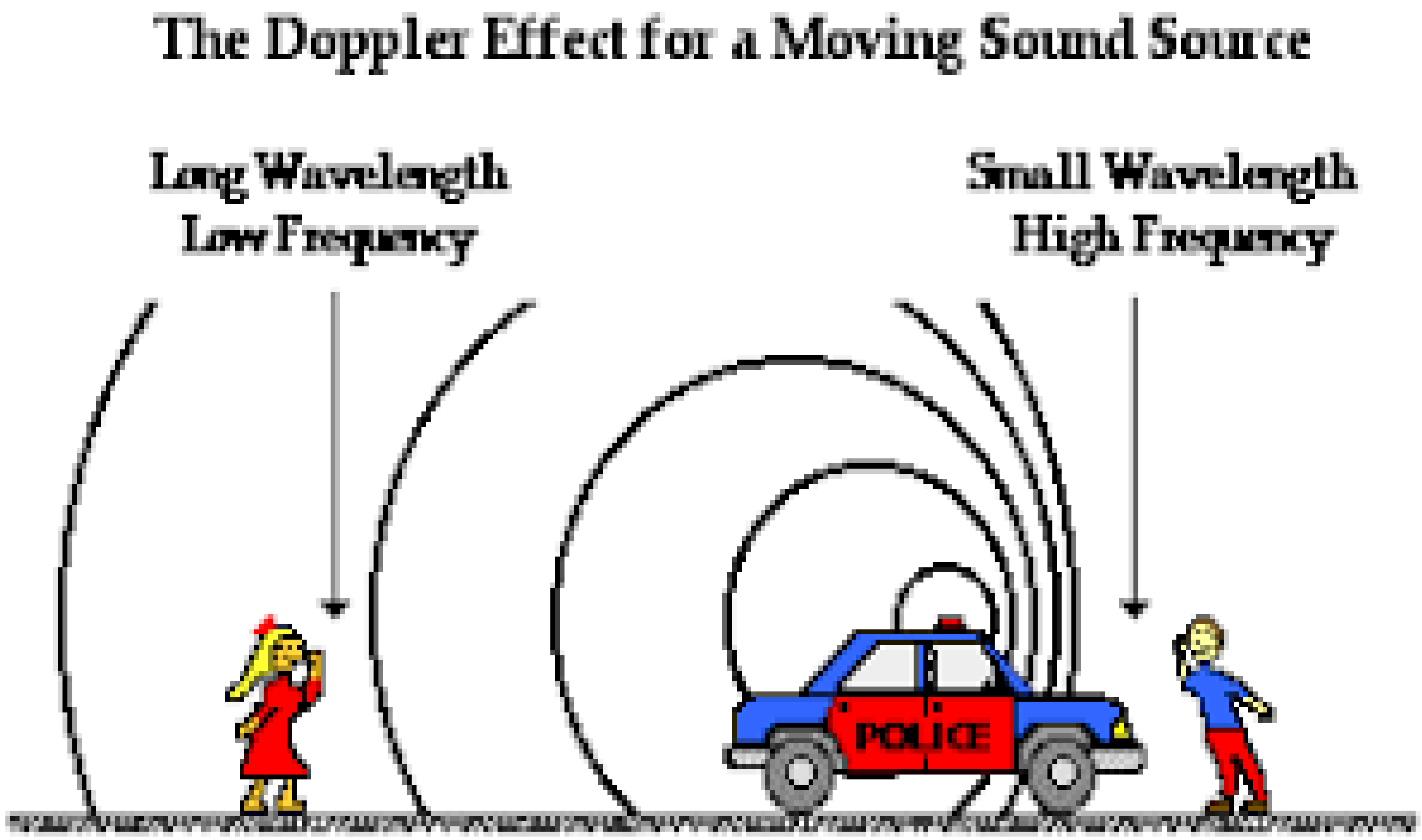
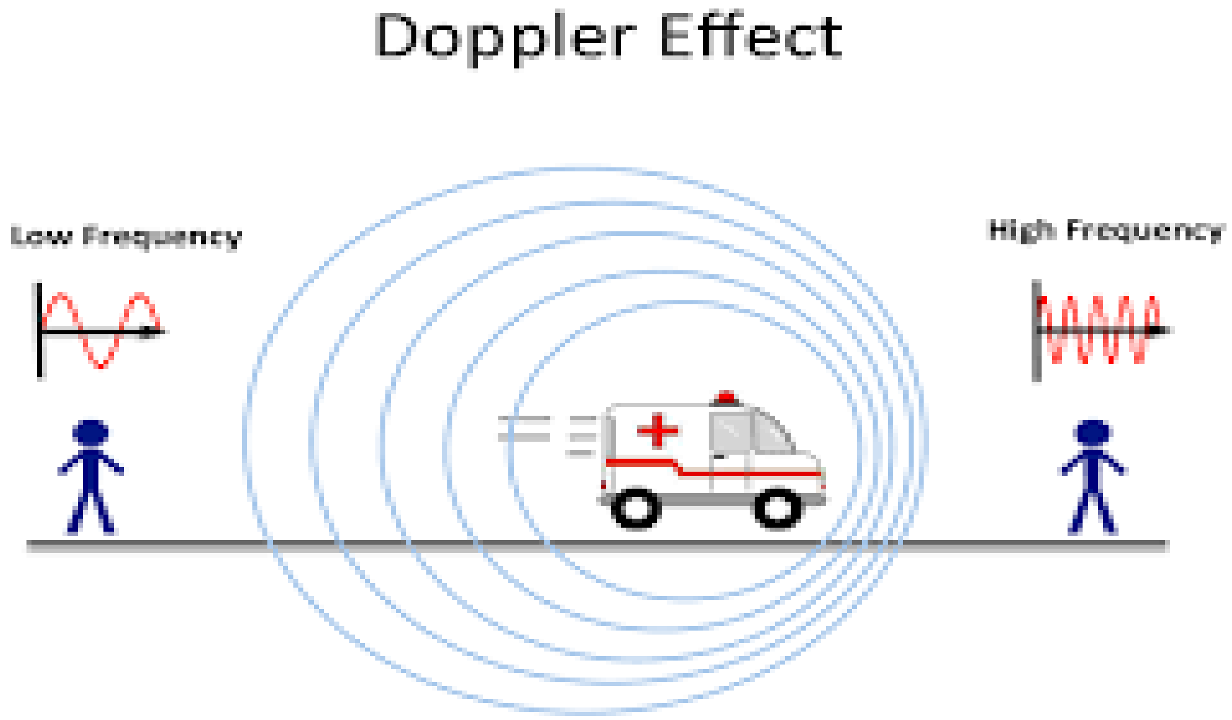
8.9 Doppler Effect



8.9 Doppler Effect

Common Properties between Doppler Effect of Sound and Light



A) Whenever there is a relative motion between observer and source of sound , the recorded frequency is different than emitted frequency.

B) Recorded frequency is higher than emitted frequency , if there is a relative approach.

C) Recorded frequency is lower than emitted frequency , if there is a relative recede.

8.9 Doppler Effect

Major differences between Doppler Effects of sound and Light

A) As the speed of light is absolute , only relative velocity between the observer and source matters i.e who is in motion does not matter.

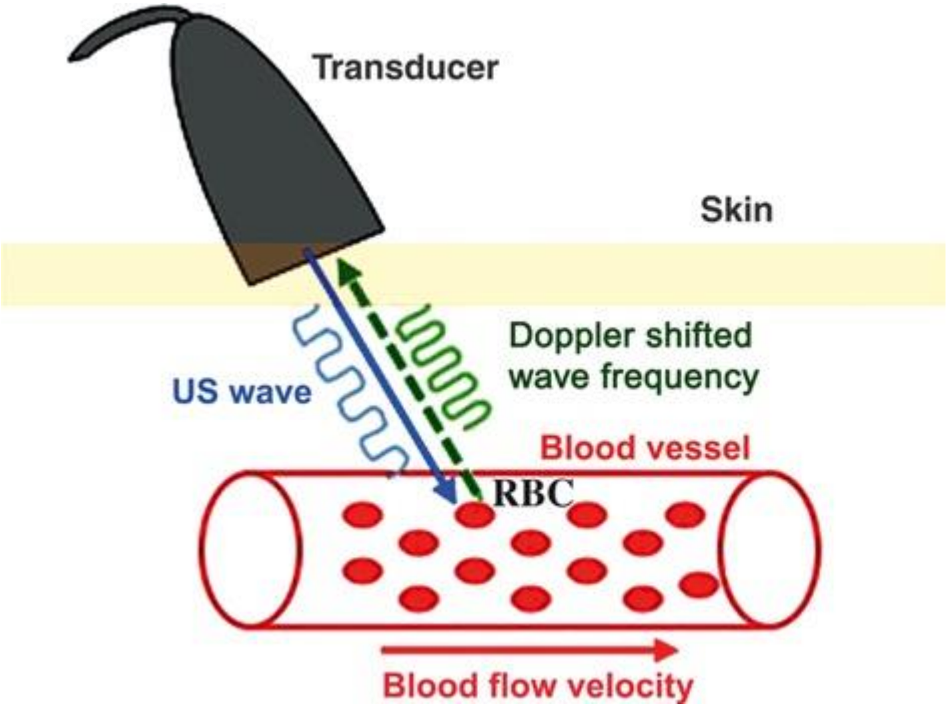
B) Classical and Relativistic Doppler effects are different in case of light, while in case of sound it is only Classical.

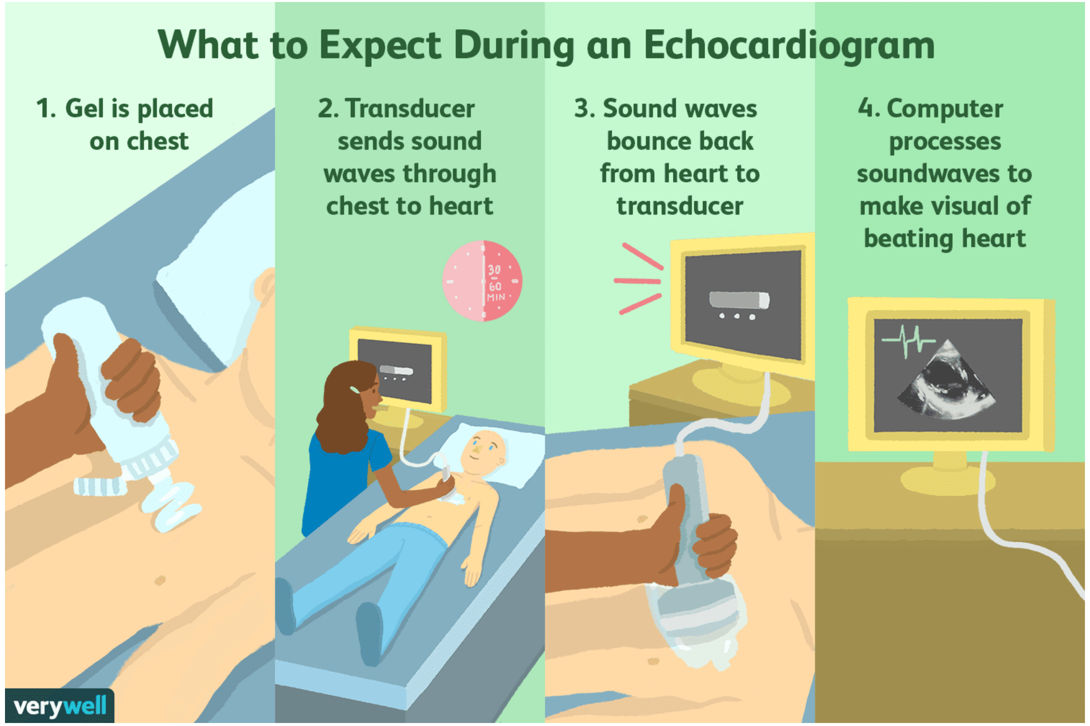
C) For obtaining exact Doppler shift for sound waves, it is absolutely important to know who is in motion.

D) Presence of wind affects the Doppler shift in sound, which is not the case in light.

8.9 Doppler Effect

Uses of Doppler effect of sound





1. In medicine, the **Doppler Effect** can be **used** to measure **the direction and speed of blood flow in arteries and veins**.

2. This is used in **echocardiograms** and **medical ultrasonography** and is an effective tool in diagnosis of vascular problems.

8.9 Doppler Effect

Uses of Doppler effect of sound

3. Doppler's effect for **animals** is commonly known as echolocation. Bats transmit sound waves through the mouth or nose. They are capable of identifying extremely thin objects, such as a strand of human hair, in dark environment.