PPP0101
PRINCIPLES OF PHYSICS

Foundation in Information Technology

ONLINE NOTES

Chapter 5(ii)
Sound Waves

5.1 Introduction

1. Sound can travel through **any material medium** with a speed that depends on the ***properties of the medium***.
2. As the waves travel, the particles in the medium vibrate to **produce density and pressure changes** along the direction of motion of the wave.
3. These changes result in a series of high pressure and low pressure regions :
    a. **high pressure regions(condensations)**
    b. **low pressure regions(rarefactions)**

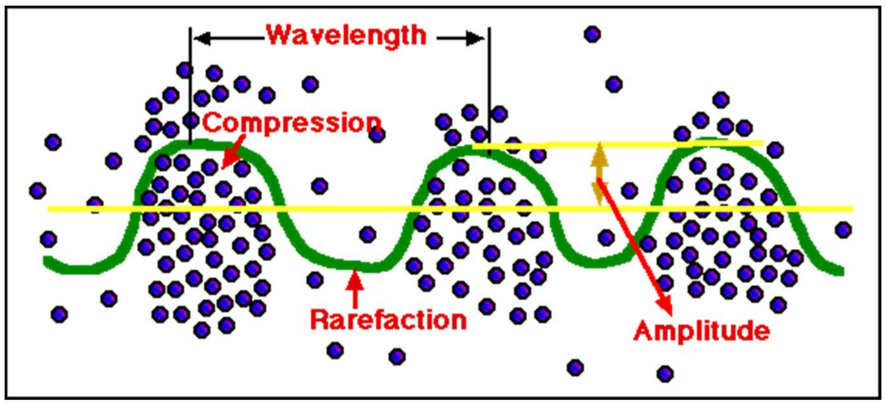

Diagram 1

5.2 Characteristics of Sound

Categories of Mechanical waves

1. Audible waves(Sound Waves)
    - Waves that lie within the range of sensitivity of the human ear.
    - Typically, 20 Hz to 20 000 Hz.

2. **Infrasonic waves**
    - Waves having frequencies below the audible range, i.e. $f < 20$ Hz.

3. **Ultrasonic waves**
    - Waves having frequencies above the audible range, i.e. $f > 20$ kHz.

Pitch

1. Pith define as how high or low a sound seems.
2. A bird makes a high pitch, meanwhile, a lion makes a low pitch.

Diagram 2 High Pitch

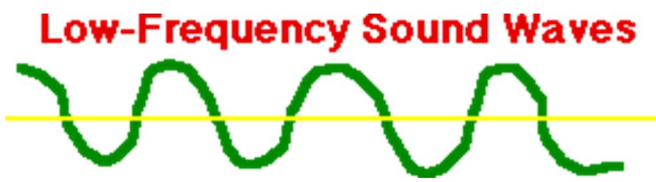

Diagram 3 Low Pitch

<u>Loudness</u>

1. Loudness is a <u>subjective</u> quantity. It is a sensation in the consciousness of a human being. A note which is regarded as being loud by one observer appears less loud to an observer whose hearing is poorer.
2. Loudness is related to the energy in the sound wave.
3. Loudness increases with intensity .

5.3 The Intensity of Sound Wave

1. The intensity of a sound wave at a place X is defined as the energy per second per meter^2 or power per meter^2, flowing normally through an area at X.

$$\textbf{Intensity } I = \frac{\left(\text{Energy } E\ (J) \,/\, \text{Time } t\ (s)\right)}{\text{Area } A\ (m^2)} = \frac{\text{Power } P\ (W)}{\text{Area } A\ (m^2)}$$

   The unit of intensity is $\mathbf{Wm^{-2}}$.

2. A spherical wave propagating radically outward from a oscillating spherical body.
3. The intensity of the spherical wave varies as $\frac{1}{r^2}$ (i.e. **Intensity** $\alpha\ \frac{\mathbf{1}}{\mathbf{r^2}}$).

4. If **P** is the average power emitted by the source, then this power at any distance r from the source must be distributed over a spherical surface of area $\mathbf{4\pi r^2}$. Therefore, the intensity I at a distance r from the source is

$$\textbf{Intensity } I = \frac{\textbf{Power, } P}{\textbf{Area, } A} = \frac{P}{4\pi r^2}$$

5. Since **P** is the same throughout any spherical surface centered at the source, the intensities at distances $\mathbf{r_1}$ and $\mathbf{r_2}$ are

$$\mathbf{I_1 = \frac{P}{4\pi r_1^2}} \qquad \text{and} \qquad \mathbf{I_2 = \frac{P}{4\pi r_2^2}}$$

5.4 Sound Level in Decibel (dB)

1. **The decibel, dB, is a unit of gain or loss in power on a logarithmic basis, using base 10 logarithms**.
2. The sound level β is defined by the equation :

   $$\beta \equiv \mathbf{10 \log \left(\frac{I}{I_O} \right) dB}$$

   Where

   $\mathbf{I_O}$ = the **reference intensity**, taken to be the threshold of hearing (chosen because it is near the lower limit of the human range of hearing)
   = $\boldsymbol{1.00 \times 10^{-12}\ Wm^{-2}}$

   I = the intensity in Wm^{-2} at the sound level, β

3. **The** threshold of pain**, I = 1.00 $\mathbf{Wm^{-2}}$ corresponds to a sound level of**

   $$\beta \equiv \mathbf{10 \log \left(\frac{I}{I_O} \right) = 10 \log \left(\frac{1.00}{1.00 \times 10^{-12}} \right) = 120\ dB}$$

4. **The** threshold of hearing **, I = 1.00 x $\mathbf{10^{-12}\ Wm^{-2}}$ corresponds to a sound level of**

   $$\beta \equiv \mathbf{10 \log \left(\frac{I}{I_o} \right) = 10 \log \left(\frac{1.00 \times 10^{-12}}{1.00 \times 10^{-12}} \right) = 0\ dB}$$

5.5 Interference of Sound Waves

1. Wave phenomenon that occur when two or more waves overlap in the same region of space are grouped under the heading **interference**.
2. One simple device for demonstrating interference of sound waves is illustrated in Figure 10.5 (a) . Two speakers, driven **in phase** by the same amplifier, emit **identical sinusoidal sound waves** with the **same constant frequency**.

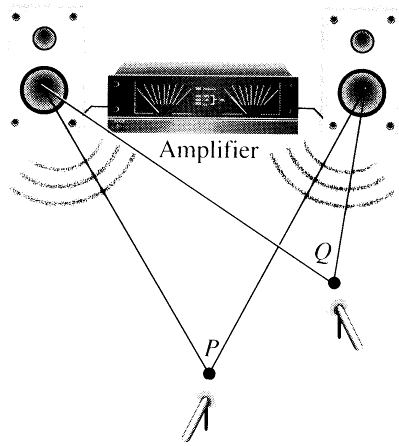

Diagram 4

<u>Beat</u>

1. **A beat is a periodic variation in intensity at a given point due to the superposition of two waves having slightly different frequencies**.

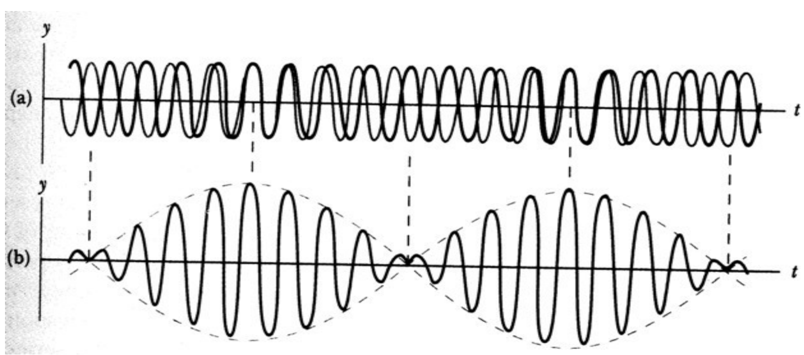

Diagram 5

5.6 Doppler Effect

1. **Doppler effect stated that a change in frequency of the wave motion should be observed when a source of sound or light was moving.**
2. In general, a Doppler effect is experienced whenever there is ***relative motion between source and observer.***
3. When the source and observer are moving **TOWARD** each other, the frequency heard by the observer is **HIGHER** than the frequency of the source.
4. When the source and observer are moving **AWAY** each other, the frequency heard by the observer is **LOWER** than the frequency of the source.

<u>Case 1</u> : **Observer O is <u>moving toward</u> the source and the sound source S is stationary**

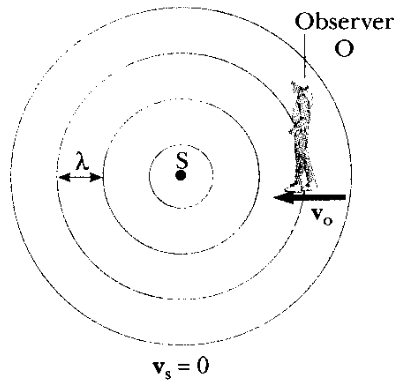

Figure 10.6 (a)

When the observer is moving toward the source, the frequency heard by the observer is :

$$\mathbf{f' = f\left[1 + \frac{v_o}{v}\right]}\ \text{Hz}$$

OR

$$f' = f\left[\frac{v + v_o}{v}\right]\ \text{Hz}$$

<u>Case 2</u> : **Observer O is <u>moving away</u> from the source and the sound source S is stationary**

When the observer is moving away from the source, the frequency heard by the observer is :

$$\mathbf{f' = f\left[1 - \frac{v_o}{v}\right]}\ \text{Hz}$$

OR

$$f' = f\left[\frac{v - v_o}{v}\right]\ \text{Hz}$$

5. In general, when an observer moves with a speed v_o relative to a stationary source, the frequency heard by the observer is :

$$\mathbf{f' = f\left[1 \pm \frac{v_o}{v}\right]}\ \text{Hz}$$

$$f' = f\left[\frac{v \pm v_o}{v}\right] \text{Hz}$$

OR

+ ve sign : when the observer moves **TOWARD** the source
- ve sign : when the observer moves **AWAY** from the source.

<u>Case 3</u> : ***The sound source S is <u>moving toward</u> the observer and the observer is stationary***

If the source S moves directly towards observer A, the wave front seen by the observer are closer together as a result of the motion of the source in the direction of the outgoing wave.

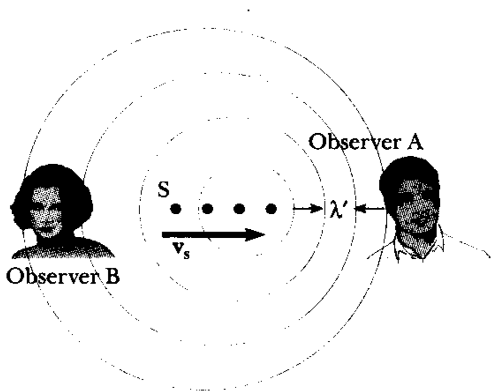

Figure 10.6 (b)

When the source is moving toward the observer, the frequency heard by the observer is :

$$\mathbf{f' = f\left(\frac{1}{1 - \frac{v_s}{v}}\right) Hz}$$

OR $$f' = f\left(\frac{v}{v - v_s}\right) \text{Hz}$$

<u>Case 4</u> : The sound source S is <u>moving away</u> from the observer and the observer is stationary

In a similar manner, when the source **<u>moves away</u>** from an observer B at rest (where observer B is to the left of the source), observer B measures wavelength λ' ***that is greater than*** λ and hears a decreased frequency

$$\mathbf{f}' = \mathbf{f}\left(\frac{\mathbf{1}}{\mathbf{1} + \frac{\mathbf{v_s}}{\mathbf{v}}}\right) \ \mathbf{Hz}$$

OR $$f' = f\left(\frac{v}{v + v_s}\right) \ \text{Hz}$$

6. In general, when a source moves with a speed $\boldsymbol{v_s}$ relative to a stationary observers, the frequency heard by the observer is :

$$\mathbf{f}' = \mathbf{f}\left(\frac{\mathbf{1}}{\mathbf{1} \mp \frac{\mathbf{v_s}}{\mathbf{v}}}\right) \ \mathbf{Hz}$$

OR $$f' = f\left(\frac{v}{v \mp v_s}\right) \ \text{Hz}$$

- ve. sign : when the source moves TOWARD the observer.
+ ve. sign : when the source moves AWAY from the observer.

Case 5 : Both the source and the observer are in motion

If both the source and the observer are in motion, we find the following general relationship for the observed frequency :

$$\mathbf{f}' = \mathbf{f}\left(\frac{\mathbf{v} \pm \mathbf{v_o}}{\mathbf{v} \mp \mathbf{v_s}}\right) \ \mathbf{Hz}$$

Note: The **upper signs** apply to **moving toward** (approach) and the **lower signs** apply to **moving away** (separation)

<u>Case 5.1</u> : Both the source and observer <u>moved toward</u> each other

$$f' = f\left(\frac{v + v_o}{v - v_s}\right) \text{ Hz}$$

<u>Case 5.2</u> : Both the source and observer <u>moved away</u> from each other

$$f' = f\left(\frac{v - v_o}{v + v_s}\right) \text{ Hz}$$

End of Chapter 5