Lesson: Sound - Summary with Formulas & Examples

1. Introduction to Sound

- Sound is a form of energy that is produced by vibrating objects and propagates as a wave through a medium.
- It requires a medium (solid, liquid, or gas) to travel and cannot propagate in a vacuum.

2. Wave Nature of Sound

- Sound waves are **longitudinal waves**, where particles of the medium vibrate **parallel** to the direction of wave propagation.
- Sound waves consist of **compressions** (regions of high pressure) and **rarefactions** (regions of low pressure).

Formula for Wave Speed

$$v = f\lambda$$

where:

- v = speed of sound (m/s),
- f = frequency of the wave (Hz),
- $\lambda = wavelength(m)$

Example:
If a sound wave has a frequency of 500 Hz and a wavelength of 0.68 m, then its speed is:

$$v = 500 \times 0.68 = 340 \text{ m/s}$$

3. Speed of Sound in Different Media

- The speed of sound depends on the medium and increases from gases to liquids to solids.

Medium	Speed of Sound (m/s)
Air (at 20°C)	343
Water	1484
Steel	5000

- Speed of sound in a gas is given by:

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

where:

- γ = adiabatic index,
- R = universal gas constant,
- T = temperature in Kelvin,
- M = molar mass of gas.

Example:
For air at 300 K, using $\gamma = 1.4$, R = 8.314 , and M = 0.029 kg/mol:

$$v = \sqrt{\frac{1.4 \times 8.314 \times 300}{0.029}} = 347 \text{ m/s}$$

4. Reflection of Sound (Echo & Reverberation)

- **Echo:** The reflection of sound when it bounces off a surface and is heard again.
- **Reverberation:** Prolonged persistence of sound due to multiple reflections.

Formula for Echo

$$d = \frac{v \times t}{2}$$

where:

- d = minimum distance of reflecting surface (m),
- v = speed of sound (m/s),
- t = minimum time interval (s).

Example:
For an echo to be heard distinctly, the minimum time gap is **0.1 seconds**. If the speed of sound is 340 m/s:

$$d = \frac{340 \times 0.1}{2} = 17 \text{ m}$$

So, the reflecting surface must be at least **17 m** away.

5. Loudness and Intensity of Sound

- **Loudness** is a subjective measure and depends on the amplitude of the sound wave.
- **Intensity** is the sound energy per unit area per unit time.

Formula for Intensity

$$I = \frac{P}{A}$$

where:

- I = intensity (W/m^2),
- P = power (W),
- A = area (m^2).

Example:
If a speaker emits **20 W** of sound energy uniformly in all directions, and we measure at **10 m** from the source:

$$I = \frac{20}{4\pi(10)^2} = \frac{20}{1256.64} = 0.0159 \text{ W/m}^2$$

6. Frequency and Pitch

- **Frequency (Hz):** The number of vibrations per second.
- **Pitch:** How high or low a sound is, determined by frequency.

Formula for Frequency of Vibrating String

$$f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

where:

- f = frequency (Hz),
- L = length of vibrating string (m),
- T = tension in the string (N),
- μ = linear mass density (kg/m).

Example:
For a string of length **0.5 m**, mass per unit length **0.01 kg/m**, and tension **100 N**:

$$f = \frac{1}{2\times0.5}\sqrt{\frac{100}{0.01}} = 5 \times 100 = 500 \text{ Hz}$$

7. Doppler Effect (Change in Frequency due to Motion)

- **Doppler Effect**: Change in frequency due to the relative motion between source and observer.

Formula for Doppler Effect

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

where:

- f' = apparent frequency,
- f = actual frequency,
- v = speed of sound,
- v_o = velocity of observer,
- v_s = velocity of source.

Example:
A police siren at **500 Hz** moves towards a stationary observer at **30 m/s** while sound speed is **340 m/s**:

$$f' = 500\left(\frac{340}{340-30}\right) = 500 \times 1.088 = 544 \text{ Hz}$$

The observer hears a higher frequency.

8. Resonance in Sound

- **Resonance**: When an object vibrates at its natural frequency due to another vibrating object of the same frequency.

Formula for Open and Closed Pipes

- **Open Pipe:**

$$f_n = \frac{nv}{2L}$$

- **Closed Pipe:**

$$f_n = \frac{(2n-1)v}{4L}$$

where:

- n = harmonic number,
- L = length of pipe.

Example:
For an open pipe of **0.5 m** and speed of sound **340 m/s**:

$$f_1 = \frac{1\times340}{2\times0.5} = 340 \text{ Hz}$$

Conclusion

This lesson covered the properties of sound, wave speed, reflection (echo), loudness and intensity, pitch, the Doppler effect, and resonance with key formulas and examples.