Chapter 4: Sound

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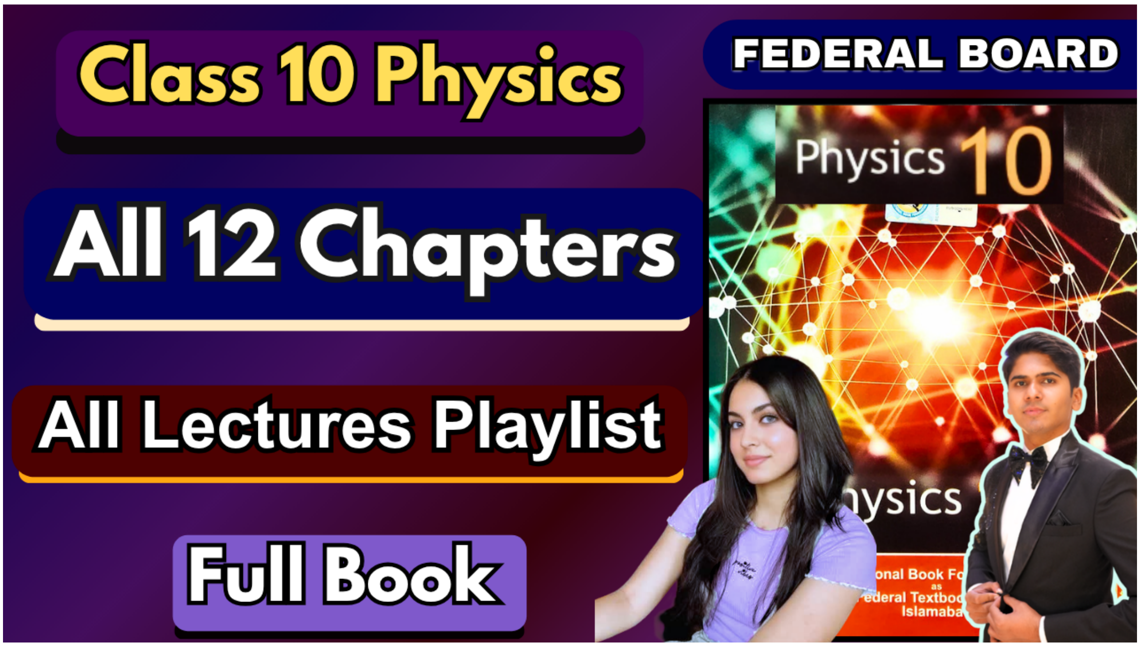

13.1 SOURCE OF SOUND

A source of sound is any object that **vibrates** to produce sound. Examples include clapping hands, ringing bells, chirping birds, and musical instruments. Sound is produced when a vibrating object transfers energy to the surrounding medium, causing compressions and rarefactions.

13.1.1 HOW SOUND IS PRODUCED?

Sound production depends on vibrations. Vibrating objects disturb nearby particles, creating pressure waves.

- **Examples:** Plucking a rubber band, striking a drum, blowing across a bottle.
- **Experiment:** Hit a tuning fork, touch it to water; vibrations disturb water, producing sound.

13.1.2 MEDIUM FOR PROPAGATION OF SOUND

Sound is a mechanical longitudinal wave, so it requires a medium (solid, liquid, or gas).

- **Bell Jar Experiment:** Let's take an electric bell and an airtight glass bell jar. The electric bell is suspended inside the airtight bell jar. The bell jar is connected to a vacuum pump, as shown in figure. The electric bell inside a vacuum jar becomes inaudible as air is removed, proving medium is essential.

13.2 NATURE OF SOUND WAVES

Sound waves are mechanical longitudinal waves consisting of **compressions** and **rarefactions** (low pressure, high velocity).

- **Compressions:** Compression is that high pressure portion within a sound wave, where molecules of medium acquire low velocity, which is produced due to vibration of object.
- **Rarefactions:** Rarefaction is that low pressure portion within a sound wave, where molecules of medium acquire high velocity, which is produced due to vibration of object.

13.3 CHARACTERISTICS OF SOUND

Sound can be distinguished from one another by three characteristics:

1. Loudness
2. Pitch
3. Quality

13.3.1 LOUDNESS

Loudness is the characteristic by which a loud sound can be distinguished from a faint sound.

- Loudness depends on the **Amplitude** of the sound wave.
- **High Amplitude** = Louder Sound
- Loudness depends on the **Sensitivity of the Listener's Ear** and the **Area of the Vibrating Body**.

13.3.2 PITCH

Pitch is the characteristic by which a sharp (high-pitched) sound can be distinguished from a dull (low-pitched) sound.

- Pitch depends on the **Frequency** of the sound wave.
- **High Frequency** = High Pitch (Sharp Sound).
- **Low Frequency** = Low Pitch (Dull Sound).

13.3.3 QUALITY (TIMBRE)

Quality is the characteristic that distinguishes two sounds of the same loudness and pitch, but produced by different instruments.

- Quality depends on the **Waveform** (or shape) of the sound wave.

13.4 THE DECIBEL SCALE

The **Decibel (dB)** is a logarithmic unit used to measure the intensity or loudness of sound, which aligns better with how the human ear perceives loudness.

- **Threshold of Hearing:** 0 dB (Faintest sound a human ear can hear).
- **Threshold of Pain:** 120 dB (Sound that causes physical pain).
- Prolonged exposure to sound above 85 dB can cause hearing damage.

13.5 MUSICAL SOUND AND NOISE

13.5.1 MUSICAL SOUND

- **Definition:** Sound that is regular, pleasant to the ear, and produced by periodic vibrations.
- **Characteristics:** Consistent pattern, single/regular frequency.
- **Examples:** Sounds from musical instruments.

13.5.2 NOISE

- **Definition:** Sound that is irregular, unpleasant to the ear, and produced by a mixture of different frequencies and amplitudes.
- **Characteristics:** Irregular waveform, sudden, high intensity.
- **Examples:** Traffic noise, jackhammer, loud bangs.

13.6 SPEED OF SOUND

The speed of sound (v) is the distance travelled by a sound wave in unit time.

- **Formula:** $v = f\lambda$ (where f is frequency, λ is wavelength).

- **Factors Affecting Speed:**

  1. **Nature of Medium:** Speed is highest in solids, followed by liquids, and lowest in gases. ($v_{\text{solid}} > v_{\text{liquid}} > v_{\text{gas}}$)
  2. **Temperature:** Speed increases as temperature increases. (Speed of sound in air at $0°$C is ~ 331 m/s).

13.7 REFLECTION OF SOUND (ECHO)

Reflection of sound is the phenomenon of sound waves bouncing back after hitting a hard surface.

- **Echo:** An echo is a reflected sound wave that reaches the listener a short time after the original sound.
- **Requirement for Clear Echo:** A minimum distance of 17.2 meters is required between the source and the reflecting surface, as the time gap between original and reflected sound must be greater than 0.1 seconds for the human ear to distinguish them.

13.8 DOPPLER EFFECT

The Doppler effect is the apparent change in the frequency (and pitch) of a sound wave for an observer who is moving relative to the sound source.

- **Source Moving Towards Observer:** Frequency (pitch) appears **higher**.
- **Source Moving Away from Observer:** Frequency (pitch) appears **lower**.
- **Application:** Used in radar (speed guns), astronomy (redshift/blueshift), and medical imaging.

13.9 ULTRASONIC WAVES (ULTRASOUND)

Ultrasonic waves are sound waves that have a frequency **higher** than the upper limit of human hearing (above $20,000$ Hz).

- **Applications:**

  1. **Medical Imaging:** Used to produce images of internal body organs (e.g., in pregnancy).
  2. **Cleaning:** Used to clean delicate equipment (e.g., jewelry, lab apparatus).

3. **Range Finding:** Used in SONAR (Sound Navigation and Ranging) to detect objects underwater (e.g., submarines, fish).
4. **Industrial:** Used to detect cracks in metal structures.

13.10 AUDIBLE FREQUENCY RANGE

The range of frequencies that a human ear can hear is from 20 Hz to $20,000$ Hz. This range decreases with age.

- **Infrasound:** Frequencies **below** 20 Hz (e.g., earthquakes, elephant calls).
- **Ultrasound:** Frequencies **above** $20,000$ Hz (e.g., bat echolocation, medical imaging).

13.11 NOISE POLLUTION

Noise pollution is excessive or disturbing sound that may harm the activity or balance of human or animal life.

13.11.1 SOURCES OF NOISE POLLUTION

1. **Traffic Noise:** Vehicular horns, engines, and air brakes.
2. **Industrial Noise:** Machinery, generators, and construction.
3. **Domestic Noise:** Loud music, electrical appliances, and yelling.
4. **Outdoor Activities:** Fireworks, concerts, and aircraft.

13.11.2 IMPORTANCE OF NOISE CONTROL

- **Health:** Prevents stress, sleep disorders, and hearing loss.
- **Productivity:** Reduces distractions in schools/workplaces.
- **Community:** Ensures quieter living environments, protects wildlife.
- **Compliance:** Meets building and noise safety regulations.

13.11.3 APPLYING ACOUSTICS IN BUILDING DESIGN

- **Absorption:** Carpets, acoustic panels reduce echo.
- **Reflection:** Materials like glass/concrete reflect sound for clarity.
- **Transmission control:** Insulated walls, windows prevent sound leakage.

- **Diffusion:** Irregular surfaces scatter sound evenly.
- **Examples:** Concert halls, offices, hospitals.

13.12 HUMAN HEARING SYSTEM

In physics, the process of converting sound into electrical signals that are interpreted by the brain involves several steps that can be described through the principles of wave mechanics, mechanical vibrations, and signal transduction.

- **Sound Waves Enter the Ear:** Sound waves enter the ear canal and strike the eardrum.

- **Eardrum Vibration:** The eardrum vibrates in response to these sound waves.
- **Ossicles Amplify Vibrations:** Ossicles (malleus, incus, stapes) amplify vibrations.
- **Vibrations Enter the Cochlea:** Vibrations pass into cochlea (fluid-filled).
- **Fluid Waves in the Cochlea:** Cochlear fluid waves stimulate basilar membranes.
- **Hair Cells Detect Vibrations:** Hair cells bend and detect vibrations.
- **Conversion to Electrical Signals:** Hair cells generate electrical signals
- **Electrical Signals Travel to the Brain:** Signals travel via the auditory nerve to the brain.

- **Brain Interprets the Signals**

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