CLASS 9 SCIENCE

Chapter 10 Notes

Sound Waves: Characteristics and Applications

Chapter focus

This chapter explains how sound is produced and propagated, sound waves as longitudinal mechanical waves, energy transfer by sound, graphical representation and characteristics of sound waves, human perception of sound, reflection, echo, reverberation, infrasonic and ultrasonic waves, echolocation and sonar.

1. Production of Sound

- Sound is produced by vibrating objects.
- Vibration is the periodic to-and-fro motion or oscillation of an object.
- A stretched rubber band produces sound while it vibrates; when its vibration stops, the sound also stops.
- Sound may be produced by vibrating strings, membranes, air columns and other vibrating objects.
- The object that produces sound is called the source of sound.
- In humans and some animals, sound is produced by the vibration of vocal cords located in the larynx or voice box.
- The tongue, lips, mouth and nasal cavity help convert the sound of the vocal cords into speech or music.
- Grasshoppers and crickets can produce sound by rubbing body parts such as wings or legs.

2. Tuning Fork

- A tuning fork is a U-shaped metal bar with a stem, usually made of steel or aluminium.
- The two arms of the U are called prongs or tines.
- When a prong is struck gently on a soft rubber pad, the prongs vibrate and produce sound.
- If a vibrating prong touches the surface of water, waves appear on the water, showing that the prong is vibrating.

Conclusion

Experiments with a rubber band and a tuning fork support the central idea that sound is produced by vibrations.

3. Propagation of Sound

- Sound can travel through solids, liquids and gases.
- The material through which sound propagates is called a medium.
- The desk activity shows that sound can travel through solids.
- The submerged-spoon activity shows that sound can travel through liquids.

Vacuum
A space containing no material medium is called a vacuum. Sound cannot propagate through a vacuum.

4. Sound Needs a Medium

- In the vacuum bell jar experiment, an electric bell is placed inside a bell jar.
- As air is removed from the jar, the bell can still be seen ringing but its sound becomes fainter.
- When a near vacuum is reached, almost no sound is heard.
- When air is allowed back into the jar, the sound becomes audible again.
- Therefore, sound needs a material medium - solid, liquid or gas - for propagation.
- Outer space is nearly a vacuum, so astronauts cannot directly hear one another during a spacewalk. They use communication devices.

5. Sound Waves: Compressions and Rarefactions

- A slinky helps model how a disturbance travels through a medium.
- The turns of a slinky alternately come closer together and spread farther apart, while each marked turn only oscillates about its own mean position.
- In air, a region of higher-than-average density is called a compression (C).
- A region of lower-than-average density is called a rarefaction (R).
- An oscillating source produces alternate compressions and rarefactions that move through the medium.

Sound wave
A disturbance consisting of a series of alternating compressions and rarefactions propagating through a medium, without actual flow of the medium's particles, is called a sound wave.

- The particles of the medium do not travel with the wave. They vibrate about their mean positions.
- A small source can produce sound waves that spread in many directions; in a simplified model, a point source produces spherical waves.

6. Longitudinal and Mechanical Nature of Sound

- In a sound wave, particles of the medium vibrate back and forth parallel to the direction of propagation.

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

Mechanical wave
A wave that requires a material medium for propagation is called a mechanical wave. Sound is a mechanical wave.

- In a transverse wave, particles vibrate perpendicular to the direction of wave propagation.
- Light can travel through vacuum and therefore is not a mechanical wave.
- Rapid expansion of heated gases can create sudden loud sound pulses. A supersonic aircraft can produce a sonic boom.

7. Energy of Sound Waves

- Sound is a form of energy.
- A loud sound near a stretched sheet can make grains placed on the sheet move because the sound wave transfers energy to the sheet.
- When a sound source vibrates, it transfers energy to the surrounding medium.
- As sound propagates, vibrating particles and their collisions transfer energy from one region to another.

Important
In sound propagation, energy is transferred; the particles of the medium themselves do not travel from the source to the listener.

- A microphone converts sound energy into electrical energy.
- A speaker does the reverse: an electrical signal makes a diaphragm or cone vibrate and produce sound.

8. Graphical Representation of a Sound Wave

- At a given instant, the density of the medium varies periodically with distance from the source.
- A sound wave can be represented by plotting distance on the x-axis and density of the medium on the y-axis.
- The average density is shown as a reference line.
- A compression corresponds to density above the average value.
- A rarefaction corresponds to density below the average value.
- The highest point of the density graph is called the crest and the lowest point is called the trough.
- The variation of density with time at a fixed location can also be used to represent a sound wave.

9. Characteristics of a Sound Wave

Wavelength

Wavelength (λ)
The distance between two consecutive crests or two consecutive troughs is called wavelength. Its SI unit is metre (m).

Frequency

Frequency (ν)
The number of density oscillations at a fixed point per unit time is called frequency. Its SI unit is hertz (Hz), equivalent to s^{-1}.

- A higher frequency means more oscillations occur each second.

Time Period

Time period (T)
The time taken for one complete density oscillation at a fixed point is called the time period. Its SI unit is second (s).

- Frequency and time period are inversely related.

Relation
$\nu = 1/T$ and $T = 1/\nu$

Amplitude

Amplitude
The amplitude of a sound wave is the maximum change in the density of air in a compression or rarefaction compared with the average density.

- A wave with larger amplitude carries more energy than a wave with smaller amplitude.

Intensity

Intensity
The amount of sound energy passing through a unit area perpendicular to the direction of propagation in unit time is called the intensity of sound.

- As sound spreads farther from its source, the same energy is distributed over a larger area, so its intensity decreases with distance.

10. Speed of Sound

Definition
The speed of sound is the distance travelled by a point on a sound wave, such as a crest or trough, in unit time.

- In one time period T, a wave travels one wavelength λ.

Wave relation
$v = \lambda/T = \lambda\nu$ or speed = wavelength × frequency

- Sound travels fastest in solids, slower in liquids and slowest in gases.
- The sound travels about 4-5 times faster in water and typically 15-20 times faster in solids than in air.
- The speed of sound in air increases with temperature and humidity.
- Examples: about 331 m s^{-1} in dry air at 0 °C and nearly 344 m s^{-1} at 22 °C.
- For ordinary media such as air, speed depends mainly on the medium, not on the source frequency. If frequency changes, wavelength changes so that $v = \lambda\nu$ remains satisfied.

11. Human Perception of Sound

Pitch

- Pitch is how humans perceive frequency.
- High-frequency sounds are generally perceived as high-pitched or shrill, such as a whistle or siren.
- Low-frequency sounds are generally perceived as low-pitched or deep, such as thunder or an aircraft rumble.

Human Audible Range

Type of sound	Frequency range
Infrasonic waves	Below 20 Hz
Human audible range	20 Hz to 20,000 Hz (20 kHz)
Ultrasonic waves	Above 20 kHz

- The exact audible range varies from person to person and generally decreases with age.
- Dogs, cats, bats and dolphins can detect ultrasound, while elephants can detect infrasound.

Loudness

- Humans perceive the amplitude of sound as loudness.
- A larger-amplitude sound is generally heard as louder; a smaller-amplitude sound is heard as softer.
- Loudness decreases as the listener moves farther from the source.
- Intensity is a measurable physical quantity, while loudness also depends on the hearing ability of the listener.
- Sound loudness is commonly expressed in decibels (dB). Normal conversation is about 60 dB.
- Unwanted or harmful sound is called noise. Prolonged exposure to loud sound can affect health, sleep and hearing.

How We Hear

- Incoming sound makes the eardrum vibrate.
- Tiny bones amplify these vibrations.
- The cochlea converts the vibrations into electrical signals that are sent to the brain and perceived as sound.
- Two ears help the brain determine the direction from which a sound arrives.

12. Tone, Musical Note and Timbre

- A tone is a sound of a single frequency, such as that produced approximately by a tuning fork or careful whistling.
- A musical note contains a fundamental frequency along with higher frequencies called overtones.
- The fundamental and overtones together create the richness of a musical sound.
- Timbre is the quality that makes different instruments sound different even when they play the same note at the same loudness.
- Timbre depends on factors such as the instrument's shape, material, construction and the pattern and intensity of overtones.
- An octave is the interval between two notes whose fundamental frequencies are in the ratio 2:1.

13. Reflection of Sound

Reflection of sound
When sound waves bounce back from an obstacle such as a solid or liquid surface, the phenomenon is called reflection of sound.

- Sound follows the same basic laws of reflection as light.
- The angle of incidence equals the angle of reflection and the incident sound, reflected sound and normal lie in the same plane.

14. Echo

Echo
An echo is a reflected sound heard separately after the original sound.

- To hear two sounds separately, the time gap between them should be at least about 0.1 s.
- Taking the speed of sound as 340 m s^{-1}, sound travels 34 m in 0.1 s.
- Because the sound travels to the reflecting surface and back, the minimum distance of the reflecting surface for a distinct echo is about 17 m under these conditions.
- Hard, smooth surfaces produce stronger reflections. Soft surfaces such as curtains absorb sound, while rough surfaces scatter it.

Echo distance formula
Distance of reflecting object = (speed of sound × total echo time) / 2

15. Reverberation

Reverberation
Persistence of sound due to multiple reflections after the source has stopped producing sound is called reverberation.

- The reverberation with reflected sounds arriving with time differences below about 0.05 s.
- Auditoriums and concert halls are designed to have desirable reverberation so that speech and music are heard clearly.
- Sound-absorbing panels, upholstered chairs, curtains and other soft porous materials help reduce unwanted reverberation.

16. Infrasonic and Ultrasonic Waves

- Infrasonic waves have frequencies below 20 Hz.
- Ultrasonic waves have frequencies above 20 kHz.
- Infrasonic waves can be used to detect natural events such as earthquakes, volcanic eruptions and severe storms.
- Ultrasound is used in ultrasonography to image internal organs without surgery.
- Ultrasound can be used to break kidney stones into smaller pieces.
- Industrial uses include ultrasonic welding, cleaning delicate machine parts and detecting internal defects in metal blocks.
- Reflected ultrasonic waves are also used to locate objects.

17. Echolocation

Echolocation
The ability to locate objects using reflected sound waves is called echolocation.

- Most bats emit short bursts of ultrasonic waves.
- The waves reflect from nearby objects and prey; by sensing the echoes, bats determine their positions.
- Dolphins, whales and some birds also use echolocation for navigation or hunting.

18. SONAR

SONAR
SONAR stands for Sound Navigation and Ranging. It uses ultrasonic waves in water and analyses the reflected waves to determine the distance, direction or motion of underwater objects.

- SONAR is useful for detecting submarines, shipwrecks and measuring ocean depth.

SONAR distance formula
Distance to object = (speed of sound in water × round-trip time) / 2

19. Important Formulae

Quantity	Formula / relation	SI unit
Frequency	ν = number of oscillations / time	Hz
Time period	$T = 1/\nu$	s
Frequency-time relation	$\nu = 1/T$	-
Wave speed	$v = \lambda\nu$	m s^{-1}
Wavelength	$\lambda = v/\nu$	m
Echo / SONAR distance	$d = vt/2$	m

20. Quick Solved Examples

Example 1 - Frequency and time period

10 oscillations occur in 2 s. Frequency = 10/2 = 5 Hz. Time period = 1/5 = 0.2 s.

Example 2 - Oscillations per minute

If frequency = 20 Hz, oscillations in 60 s = 20 × 60 = 1200.

Example 3 - Echo

An echo is heard after 0.5 s and speed of sound is 340 m s^{-1}.

Distance from wall = (340 × 0.5)/2 = 85 m.

Example 4 - SONAR

A sonar echo returns after 0.90 s in seawater where speed = 1530 m s^{-1}.

Distance = (1530 × 0.90)/2 = 688.5 m.

Example 5 - Wave relation

If $v = 344$ m s^{-1} and $\lambda = 3.44$ m, then $\nu = v/\lambda = 100$ Hz and $T = 1/100 = 0.01$ s.

21. Important Distinctions

Pair	Difference
Compression vs rarefaction	Compression has density above average; rarefaction has density below average.
Longitudinal vs transverse wave	Particle vibration is parallel to propagation in longitudinal waves and perpendicular in transverse waves.
Frequency vs time period	Frequency is oscillations per second; time period is time for one oscillation. They are inversely related.
Amplitude vs intensity	Amplitude describes maximum density variation; intensity is sound energy passing per unit area per unit time.
Pitch vs loudness	Pitch mainly relates to frequency; loudness is the human perception associated with amplitude and hearing sensitivity.
Echo vs reverberation	Echo is a separately heard reflected sound; reverberation is persistence due to multiple closely spaced reflections.
Infrasonic vs ultrasonic	Infrasonic: below 20 Hz; ultrasonic: above 20 kHz.

22. Key Terms

Term	Meaning
Vibration	Periodic to-and-fro motion of an object.
Source	Object that produces sound.
Medium	Material through which sound propagates.
Compression	Region of higher-than-average density.
Rarefaction	Region of lower-than-average density.
Sound wave	Alternating compressions and rarefactions travelling through a medium.
Longitudinal wave	Particles vibrate parallel to wave propagation.
Mechanical wave	Wave that requires a material medium.
Wavelength	Distance between consecutive crests or troughs.
Frequency	Number of oscillations per unit time.
Time period	Time taken for one complete oscillation.
Amplitude	Maximum density change from average density.
Intensity	Sound energy passing per unit area per unit time.
Pitch	Human perception of frequency.
Timbre	Quality that distinguishes sounds from different sources.
Echo	Reflected sound heard separately.
Reverberation	Persistence of sound due to multiple reflections.
Echolocation	Locating objects by reflected sound.
SONAR	Sound Navigation and Ranging using reflected sound, usually ultrasound underwater.

23. Exam-Oriented Self-Check Questions

1. How is sound produced? Explain with the rubber-band or tuning-fork activity.
2. Define vibration and source of sound.
3. How do humans produce sound?
4. Show that sound can travel through solids and liquids.
5. Describe the vacuum bell jar experiment. What does it prove?
6. Define compression and rarefaction.
7. Explain how a sound wave propagates through air without transporting air particles from source to listener.
8. Why is sound called a longitudinal mechanical wave?
9. How do sound waves transfer energy?
10. Explain the graphical representation of a sound wave in terms of density and distance.
11. Define wavelength, frequency and time period and state their SI units.
12. Write and explain the relation between frequency and time period.
13. Define amplitude and intensity. How are amplitude and energy related?
14. Derive the relation $v = \lambda\nu$.
15. How does the speed of sound depend on the medium, temperature and humidity?
16. Define pitch and loudness. How are they related to frequency and amplitude?
17. State the human audible range. Define infrasonic and ultrasonic waves.
18. Differentiate between a tone, a musical note and timbre.
19. State the laws of reflection of sound.
20. What is an echo? Why is a minimum distance needed to hear a distinct echo?
21. Define reverberation. How is excessive reverberation reduced in auditoriums?
22. Give important applications of infrasonic and ultrasonic waves.
23. Explain echolocation in bats.
24. Explain the working principle of SONAR and write its distance formula.

One-Minute Chapter Summary

Quick revision

Sound is produced by vibrations and requires a material medium for propagation. It travels through solids, liquids and gases as a longitudinal mechanical wave consisting of compressions and rarefactions. The particles of the medium oscillate about their mean positions while energy is transferred through the wave. Sound waves are described by wavelength, frequency, time period, amplitude, intensity and speed, with $\nu = 1/T$ and $v = \lambda\nu$. Human perception includes pitch, loudness and timbre. Sound reflects from surfaces, producing phenomena such as echo and reverberation. Humans generally hear from 20 Hz to 20 kHz; frequencies below and above this range are infrasonic and ultrasonic. Reflected ultrasound is used in echolocation, SONAR, medicine and industry.

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