Chapter 10: Sound Waves: Characteristics and Applications

Exercises — Revise, Reflect, Refine

Q1 Which observation best supports the idea that sound is a mechanical wave?
(i) Sound shows reflection
(ii) Sound needs a medium to propagate
(iii) Sound has frequency
(iv) Sound carries energy

SOLUTION

A mechanical wave is defined as a wave that requires a material medium (solid, liquid, or gas) for its propagation — it transfers energy through the oscillation of the medium's particles.

(i) Reflection is a property of all waves, including electromagnetic waves; it does not distinguish mechanical from non-mechanical waves.

(ii) Sound cannot travel through vacuum. This is precisely because it is a mechanical wave — it needs particles of the medium to vibrate and pass the disturbance forward. Electromagnetic waves (light, radio) need no medium, so the requirement of a medium directly identifies sound as mechanical.

(iii) Frequency is a property of any periodic wave; it does not indicate whether a medium is needed.

(iv) All waves carry energy; energy transport alone does not indicate a mechanical wave.

Answer: (ii) Sound needs a medium to propagate.

Q2 For a sound wave propagating in a medium, increasing its frequency will increase its
(i) wavelength
(ii) speed
(iii) number of compressions per second
(iv) time period

SOLUTION

The wave speed in a given medium at constant temperature and pressure depends on the properties of the medium (density, elasticity), not on the frequency. So increasing frequency does NOT change speed.

The wave equation is: v = f × λ. Since v is constant, λ = v/f — increasing f decreases λ (wavelength).

The time period T = 1/f — increasing f decreases T.

The number of compressions passing a point per second equals the frequency. If frequency increases, more compressions pass per second.

Answer: (iii) Number of compressions per second.

Q3 If 20 compressions pass a point in 4 seconds, the frequency is

(i) 80 Hz

(ii) 5 Hz

(iii) 10 Hz

(iv) 0.2 Hz

SOLUTION

Frequency is defined as the number of complete oscillations (or compressions) per unit time.

f = (number of compressions) / (time) = 20 / 4 = 5 Hz

Answer: (ii) 5 Hz.

Q4 In a room, the reflected sound reaches the ear 0.05 s after its production. Will it produce an echo or reverberation? Justify your answer.

SOLUTION

For a distinct echo to be heard, the reflected sound must reach the ear at least 0.1 s after the original sound. This is because the human ear can distinguish two sounds only if there is a time gap of 0.1 s or more between them.

Here the reflected sound arrives 0.05 s after production — this is less than 0.1 s.

Since the time gap is too small for the ear to perceive the reflected sound as a separate sound, the two sounds (original and reflected) overlap and merge, prolonging the original sound.

This persistence of sound due to repeated reflections is called reverberation.

Answer: Reverberation. Since the reflected sound arrives only 0.05 s after production (less than the 0.1 s minimum needed for a distinct echo), the sounds overlap and the original sound appears prolonged — this is reverberation, not an echo.

Q5 Graphs representing two sound waves are given in Fig. 10.30. If the scales on the X and Y axes of the two graphs are the same, which of the two sound waves has (i) greater wavelength, and (ii) smaller amplitude?

SOLUTION

From Fig. 10.30 (both axes at the same scale):

Graph (a) shows fewer, more spread-out oscillations over the same distance. The crests and troughs are farther apart, indicating a longer distance between successive compressions (or rarefactions).

Graph (b) shows many more tightly packed oscillations over the same distance, indicating a shorter distance between successive compressions.

(i) Greater wavelength: Graph (a) has fewer cycles over the same horizontal span, so the distance between consecutive crests is larger — graph (a) has the greater wavelength.

(ii) Smaller amplitude: The Y-axis represents density variation. Measured about the dashed mean line, graph (a)'s crests and troughs reach a smaller peak-to-mean deviation than graph (b)'s (whose peaks and troughs extend farther from the mean). Therefore graph (a) has the smaller amplitude.

Answer: (i) Graph (a) has the greater wavelength. (ii) Graph (a) has the smaller amplitude.

Q6 The sound waves emitted by three sources A, B and C are represented in Fig. 10.31. If the frequency of A is maximum and C is minimum, identify the corresponding curves, and mark A, B and C on them.

SOLUTION

Frequency is the number of complete cycles (compressions + rarefactions) per unit length at any given instant — equivalently, the curve with the most oscillations packed into a given horizontal distance has the highest frequency.

From Fig. 10.31, three sinusoidal curves are overlaid on the same distance axis:

The curve with the greatest number of oscillations per unit distance corresponds to the highest frequency — this is wave A.

The curve with the fewest oscillations per unit distance corresponds to the lowest frequency — this is wave C.

The remaining curve, with an intermediate number of oscillations, corresponds to wave B.

Answer: A = the curve with the most oscillations per unit distance (highest frequency); C = the curve with the fewest oscillations (lowest frequency); B = the intermediate curve.

Q7 Draw a graph to represent a sound wave for which the density amplitude is 3 units and wavelength is 4 cm.

SOLUTION

A sound wave is represented as a plot of density (or density variation from mean) on the Y-axis against distance on the X-axis.

Density amplitude = 3 units: the wave oscillates from +3 (compression) to −3 (rarefaction) about the mean density level (taken as 0).

Wavelength = 4 cm: one complete cycle (one compression + one rarefaction, i.e., one full sinusoidal period) spans 4 cm along the X-axis.

Draw a sinusoidal curve with: Y-axis range from −3 to +3 units; X-axis marked in cm; crests at Y = +3 and troughs at Y = −3; the first complete cycle finishing at x = 4 cm, second at x = 8 cm, etc.

The graph is: $y(x) = 3 \sin(2\pi x / 4) = 3 \sin(\pi x/2)$, with x in cm.

Answer: A sinusoidal wave with amplitude 3 units (peaks at +3, troughs at −3 on the density axis) and one full cycle every 4 cm along the distance axis.

Q8 In a movie, while showing the explosion of a spacecraft in space, a flash of light is shown along with sound at the same time. What are the errors in this depiction?

SOLUTION

Error 1 — Sound cannot travel through space (vacuum): Sound is a mechanical wave and requires a material medium (particles of a solid, liquid, or gas) to propagate. Outer space is essentially a vacuum with no particles. Therefore, the explosion of a spacecraft in space would produce no sound that could reach an observer. Showing sound accompanying the explosion is scientifically incorrect.

Error 2 — Light and sound would not arrive simultaneously (even if a medium existed): Light travels at approximately 3×10^8 m s^{-1}, whereas sound travels at only about 340 m s^{-1} in air. Even if there were air in space, the sound would reach an observer much later than the light. Showing them simultaneously is also an error.

Error 3 — The depiction implies sound travels through vacuum: By showing sound at all, the movie implicitly and incorrectly suggests that sound does not need a medium.

Answer: Two errors: (1) Sound cannot travel through the vacuum of space — there is no medium for sound to propagate, so no sound would be heard at all. (2) Even if a medium existed, sound travels far slower than light, so they would not arrive simultaneously.

Q9 A source produces a sound wave of wavelength 3.44 m. If the wave travels with a speed of 344 m s^{-1}, find its time period.

SOLUTION

Given: wavelength $\lambda = 3.44$ m; speed $v = 344$ m s^{-1}.

Step 1 — Find frequency using $v = f \times \lambda$:

$f = v / \lambda = 344 / 3.44 = 100$ Hz

Step 2 — Find time period $T = 1/f$:

$T = 1 / 100 = 0.01$ s

Answer: Time period T = 0.01 s.

Q10 A ship searching for a sunken ship sent a sonar signal and detected an echo after 5 s. If ultrasonic wave travels at 1525 m s^{-1} in seawater, approximately how far down in the ocean is the wreckage of the sunken ship located?

SOLUTION

Given: time for echo = 5 s; speed of ultrasonic wave in seawater v = 1525 m s^{-1}.

The ultrasonic signal travels down to the wreck and back, so the total distance covered = $v \times t = 1525 \times 5 = 7625$ m.

The depth to the wreck = total distance / 2 = 7625 / 2 = 3812.5 m.

Answer: The wreckage is approximately 3812.5 m (about 3.8 km) below the surface.

Q11 A vehicle is fitted with an ultrasonic distance sensor as part of parking assistance system which provides echolocation, while the driver is reversing the vehicle. It emits ultrasonic wave (about 40 kHz) which is reflected by the obstacle. When the warning beep starts sounding at a distance of 1.2 m from the obstacle, how much time is taken by ultrasonic wave to travel to the obstacle and come back? Assume the speed of ultrasonic wave in air to be 345 m s^{-1}.

SOLUTION

Given: distance to obstacle d = 1.2 m; speed of ultrasonic wave v = 345 m s^{-1}.
The ultrasonic wave travels from the sensor to the obstacle and back, so total distance = 2 × 1.2 = 2.4 m.
Time = total distance / speed = 2.4 / 345 ≈ 0.00696 s ≈ 6.96 × 10^{-3} s

Answer: Time ≈ 6.96 × 10^{-3} s (approximately 7 ms).

Q12 The speed of sound in air is about 331 m s^{-1} at 0 °C and nearly 344 m s^{-1} at 22 °C. Roughly how much extra time will the sound of thunder take to travel a distance of 1720 m, if the air temperature changes from 22 °C to 0 °C? Assume that all other conditions remain unchanged.

SOLUTION

Given: distance = 1720 m; v at 22 °C = 344 m s^{-1}; v at 0 °C = 331 m s^{-1}.
Time at 22 °C: t_1 = 1720 / 344 = 5.00 s
Time at 0 °C: t_2 = 1720 / 331 ≈ 5.196 s
Extra time = $t_2 - t_1$ = 5.196 − 5.00 ≈ 0.196 s ≈ 0.2 s

Answer: The sound of thunder takes approximately 0.2 s extra to travel 1720 m at 0 °C compared to 22 °C.

Q13 The variation of density of medium for a sound wave propagating with a speed of 340 m s^{-1} is shown in Fig. 10.32. Calculate the wavelength and frequency of the sound wave.

SOLUTION

From Fig. 10.32: the density pattern shows repeating compression (dense) and rarefaction (sparse) regions. The 8 cm scale bar spans from one compression to the next-but-one compression — i.e., two complete wavelengths (three compression bands lie under it, so the bar covers two full compression-to-compression cycles).

Therefore: 2λ = 8 cm, so wavelength λ = 4 cm = 0.04 m.
Given: speed v = 340 m s^{-1}.
Frequency f = v / λ = 340 / 0.04 = 8500 Hz.

Answer: Wavelength = 4 cm (0.04 m); Frequency = 8500 Hz.

Q14 The graphical representation of two sound waves A and B propagating at the same speed of 345 m s^{-1} is shown in Fig. 10.33. What is the wavelength of each of them? Also, calculate their frequencies.

SOLUTION

From Fig. 10.33: the X-axis (distance) runs from 0 to 5.0 cm with a mid-mark at 2.5 cm.
Wave A (the labelled curve with the larger amplitude): two complete cycles fit within the 5.0 cm span, so λ_A = 5.0 / 2 = 2.5 cm = 0.025 m.
Wave B (the labelled curve with the smaller amplitude): one complete cycle occupies the full 5.0 cm span, so λ_B = 5.0 cm = 0.05 m.
Both waves travel at v = 345 m s^{-1}.
Frequency of A: f_A = v / λ_A = 345 / 0.025 = 13800 Hz = 13.8 kHz
Frequency of B: f_B = v / λ_B = 345 / 0.05 = 6900 Hz = 6.9 kHz

Answer: Wave A: λ = 2.5 cm, f = 13800 Hz. Wave B: λ = 5.0 cm, f = 6900 Hz.

Q15 Two identical sound sources are placed at A and B — one in air and one submerged in water (Fig. 10.34). Both produce sounds at the same time, which travel horizontally to the vertical side of the cliff and come back. If the time taken by the sound to return to A is 4.5 times than that of B, what is the ratio between the speeds of sound in air and water?

SOLUTION

Let the horizontal distance from both sources to the cliff be d (same for A and B, since they are at the same horizontal distance).
Let v_air = speed of sound in air; v_water = speed of sound in water.
Time for sound to return to A (in air): t_A = 2d / v_air
Time for sound to return to B (in water): t_B = 2d / v_water
Given: t_A = 4.5 × t_B
=> 2d / v_air = 4.5 × (2d / v_water)
=> 1 / v_air = 4.5 / v_water

=> v_air / v_water = 1 / 4.5 = 2 / 9

Answer: The ratio of the speed of sound in air to the speed of sound in water = 2 : 9.