Class 11 Physics · Chapter 14: Waves

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. A harmonic wave of amplitude 3.0 cm and wavelength 0.50 m travels along the +x direction at 20 m s^{-1}. At x = 0 and t = 0 the displacement is zero. With x in metres and t in seconds, the wave is described by [1]

(a) $y = 0.030 \sin(4\pi x + 80\pi t)$ m
(b) $y = 0.030 \sin(4\pi x - 40\pi t)$ m
(c) $y = 0.030 \sin(4\pi x - 80\pi t)$ m
(d) $y = 0.030 \sin(0.50x - 20t)$ m

Answer: (c) $k = 2\pi/\lambda = 2\pi/0.50 = 4\pi$ m^{-1}. $\nu = v/\lambda = 20/0.50 = 40$ Hz, so $\omega = 2\pi\nu = 80\pi$ s^{-1}. A wave along +x has the form $a \sin(kx - \omega t)$. The + sign gives a wave along −x; $40\pi t$ drops the 2 in $\omega = 2\pi\nu$; $0.50x - 20t$ puts λ and ν where k and ω belong.

2. A mechanical wave set up by a loudspeaker travels through the air in a closed hall. This wave must be [1]

(a) transverse, since the air molecules move up and down
(b) longitudinal, since air cannot sustain a shearing stress
(c) electromagnetic, since it travels without a solid medium
(d) either transverse or longitudinal, depending on the loudspeaker

Answer: (b) Transverse waves need a medium that can sustain shearing stress, which a fluid such as air cannot. Fluids sustain compressive strain, so only longitudinal mechanical waves travel through air.

3. Two points on a string carrying a harmonic wave of frequency 40 Hz are 15 cm apart. They are less than one wavelength apart, and the phase difference between their oscillations is $\pi/3$. The speed of the wave is [1]

(a) 18 m s^{-1}
(b) 36 m s^{-1}
(c) 6.0 m s^{-1}
(d) 72 m s^{-1}

Answer: (b) A phase difference of 2π corresponds to one wavelength, so $\pi/3$ corresponds to $\lambda/6$. $\lambda = 6 \times 0.15 = 0.90$ m and $v = \lambda\nu = 0.90 \times 40 = 36$ m s^{-1}. 18 m s^{-1} takes $\pi/3$ as a third of a wavelength; 6.0 m s^{-1} multiplies the separation by the frequency.

4. A sound wave travels from a loudspeaker to a listener 10 m away. What is carried from the loudspeaker to the listener? [1]

(a) the layers of air next to the loudspeaker
(b) a steady stream of air, like a wind
(c) energy, while each layer of air only oscillates about its mean position
(d) nothing; the air near the listener vibrates on its own

Answer: (c) In a wave, energy and not matter is transferred. Sound travels as compressions and rarefactions; each layer of air oscillates about its mean position, unlike a wind, which is a motion of air as a whole.

5. A stationary wave of wavelength 60 cm is set up on a string. The distance between a node and the antinode next to it is [1]

(a) 15 cm
(b) 30 cm
(c) 60 cm
(d) 7.5 cm

Answer: (a) Successive nodes are $\lambda/2$ apart and an antinode lies midway between two nodes, so a node and the adjacent antinode are $\lambda/4 = 60/4 = 15$ cm apart. 30 cm is the node-to-node distance.

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6. By what percentage must the tension in a stretched wire be increased so that its fundamental frequency rises by 10%, the length being kept the same? [2]

$v = (1/2L)\sqrt{(T/\mu)}$, so $v \propto \sqrt{T}$ and $T \propto v^2$. $T_2/T_1 = (1.10)^2 = 1.21$. The tension must be increased by 21%.

- $v \propto \sqrt{T}$, so $T \propto v^2$ (1)
- $T_2/T_1 = 1.21$: an increase of 21% (1)

7. A row of railway bogies stands at a station, each coupled to the next by a spring coupling. An engine gives a sudden push to the first bogie. Explain how the push reaches the last bogie, and state what this shows about a wave. [2]

The push compresses the first coupling, which pushes the second bogie; its coupling compresses and pushes the third, and so on, so the push passes from bogie to bogie along the train. Each bogie moves only a little and the train as a whole is not moved. A wave likewise carries a disturbance, with its energy, through a medium whose parts only move about their own positions; the medium as a whole does not travel.

- the push is passed on from bogie to bogie through the spring couplings (1)
- the train as a whole does not move: a wave carries the disturbance (energy), not the medium (1)

8. A transverse harmonic wave of amplitude 2.0 cm, wavelength 40 cm and frequency 25 Hz travels along the −x direction on a string. The displacement at x = 0 is zero at t = 0. Write the equation of the wave, with x in metres and t in seconds. [2]

$k = 2\pi/\lambda = 2\pi/0.40 = 5\pi \approx 15.7\ m^{-1}$ and $\omega = 2\pi\nu = 2\pi \times 25 = 50\pi \approx 157\ s^{-1}$. A wave along −x has the form $a \sin(kx + \omega t + \phi)$, and $\phi = 0$ since $y = 0$ at $x = 0$, $t = 0$. So $y = 0.020 \sin(5\pi x + 50\pi t)$ m.

- $k = 5\pi\ m^{-1}$ and $\omega = 50\pi\ s^{-1}$ (1)
- $y = 0.020 \sin(5\pi x + 50\pi t)$, with the + sign for −x (1)

9. An air column resonates at 150 Hz, 250 Hz and 350 Hz, and at no frequency in between. The speed of sound is 340 m s^{-1}. Is the column closed at one end or open at both ends? Find its fundamental frequency and its length. [3]

Successive resonances differ by 100 Hz. If the pipe were open at both ends, all harmonics would appear and the fundamental would be 100 Hz; but 150 Hz is not a multiple of 100 Hz. For a pipe closed at one end only odd harmonics appear, spaced by $2\nu_1$: $\nu_1 = 100/2 = 50$ Hz, and 150, 250, 350 Hz are its 3rd, 5th and 7th harmonics. So the pipe is closed at one end, and $L = v/4\nu_1 = 340/(4 \times 50) = 1.7$ m.

- closed at one end: the frequencies are in the ratio 3 : 5 : 7 (1)
- fundamental 50 Hz (1)
- $L = v/4\nu_1 = 1.7$ m (1)

10. For the travelling wave $y(x, t) = a \sin(kx - \omega t)$, follow a point of constant phase to show that the wave speed is $v = \omega/k$, and hence that $v = \lambda\nu$. State what $v = \lambda\nu$ means physically. [3]

A point of fixed phase, such as a crest, moves so that $kx - \omega t$ stays constant. If it moves Δx in time Δt, $k(x + \Delta x) - \omega(t + \Delta t) = kx - \omega t$, so $k\Delta x - \omega\Delta t = 0$ and, in the limit, $dx/dt = \omega/k = v$. With $\omega = 2\pi\nu$ and $k = 2\pi/\lambda$, $v = 2\pi\nu/(2\pi/\lambda) = \lambda\nu = \lambda/T$. Physically: in the time an element of the medium takes for one full oscillation, the wave pattern travels one wavelength.

- $kx - \omega t$ = constant for a moving phase point (1)
- $k\Delta x = \omega\Delta t$, so $v = \omega/k$ (1)
- $\omega = 2\pi\nu$, $k = 2\pi/\lambda$ give $v = \lambda\nu$; meaning: the pattern moves λ in one period (1)

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11. A pulse of height 5 mm travels along a stretched string towards its end. Describe the reflected pulse, with reasons, when the end is (a) tied to a rigid wall, and (b) tied to a light ring that slides freely on a smooth vertical rod. In case (b), what is the greatest displacement of the end? [3]

(a) At a rigid end the displacement must be zero at all times; by superposition this needs a reflected pulse differing in phase by π, so the pulse returns inverted, of the same shape and height if no energy is absorbed (the wall pulls back on the string, by Newton's third law). (b) At a free end there is no phase change: the pulse returns upright, with the same height. The incident and reflected pulses add at the end, so the end rises to twice the pulse height, 10 mm.

- rigid end: inverted, phase change π, with reason (1)
- free end: upright, no phase change (1)
- greatest displacement of the free end 2 × 5 = 10 mm (1)

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