Singapore Top JC **Integrated** questions with worked solutions

WAVE MOTION

Compiled and selected by The Physics Cafe

1 Bats emit high frequency sound waves and receive reflected echoes. They use the echoes to locate their position. This process is called echolocation.

Fig. 8.1 illustrates this process.

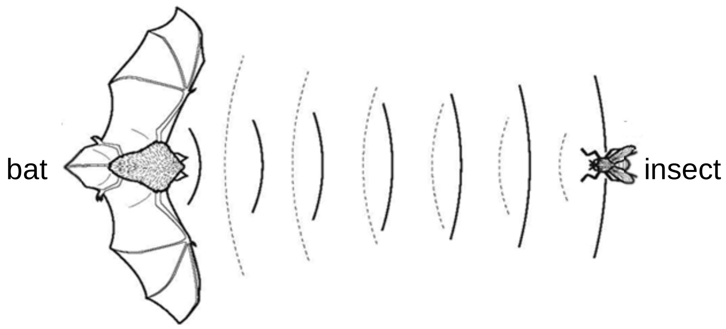


Fig. 8.1

(a) Sound waves emitted by the bat travel at 340 m s^{-1}. Their typical frequency range is 20 kHz to 80 kHz.

Calculate the range of wavelengths for this frequency range.

range of wavelength = ………………………….mm [2]

(b) Bats emit two waveforms, wave B and wave P, which superpose to form wave E.

- Wave B (shown in Fig. 8.2) gives information about the surrounding background.
- Wave P (not shown in Fig. 8.2) enables the bat to detect insect prey.
- Wave E (shown in Fig. 8.2) is the superposition of wave B and wave P.

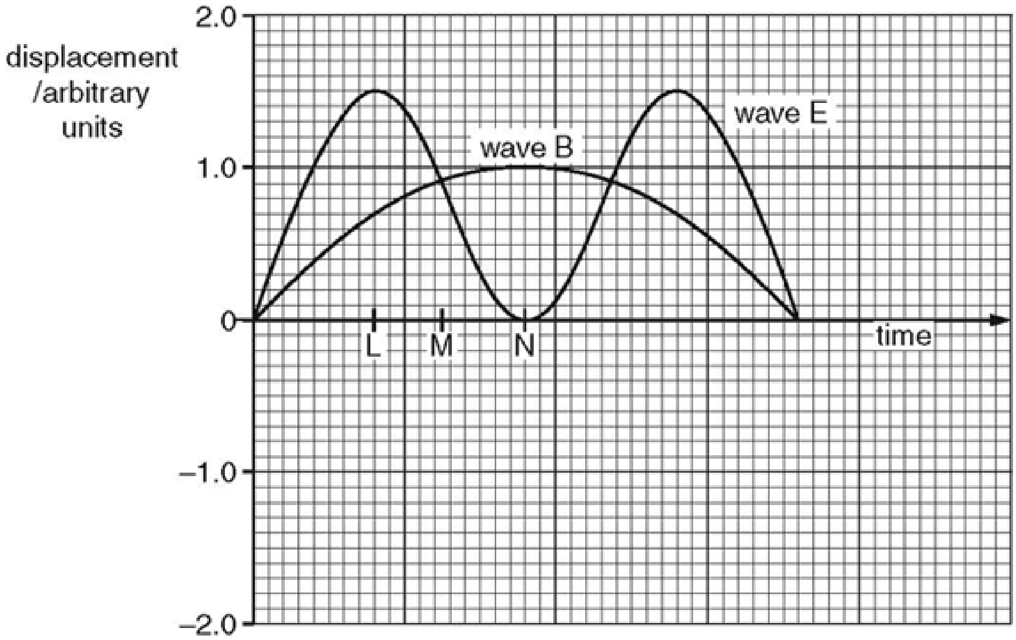


Fig. 8.2

(i) Use the principle of superposition to determine the displacement of wave P at times corresponding to points L, M and N on the time axis.

Write the displacement values in the spaces provided.

displacement of wave P at L = ... units

displacement of wave P at M = ... units

displacement of wave P at N = ... units [2]

(ii) Hence draw the waveform for wave P on Fig. 8.2. [2]

2 Two loudspeakers emit sound waves of frequency 680 Hz in phase with each other. A listener is 8.0 m from loudspeaker A and 11.0 m from loudspeaker B. At this location each loudspeaker alone would result in sound intensity I_o. The speed of sound is 340 m s^{-1}.

(a) Determine the phase difference between the waves as they arrive at the listener.

phase difference = ………………rad [2]

(b) Determine the resultant sound intensity that the listener hears. Express your answer in terms of I_o.

resultant intensity = ……………………… [2]

(c) Determine the ratio of the power of loudspeaker A to the power of loudspeaker B, assuming the loudspeakers are point sources of sound.

ratio = ……………………… [2]

(d) The loudspeakers are decoupled so that they are no longer in phase but the frequency remains the same as each other. The sound waves arriving at the location of the listener are adjusted such that they arrive $\frac{\pi}{2}$ radians out of phase at the listener's location as shown in Fig. 4.1.

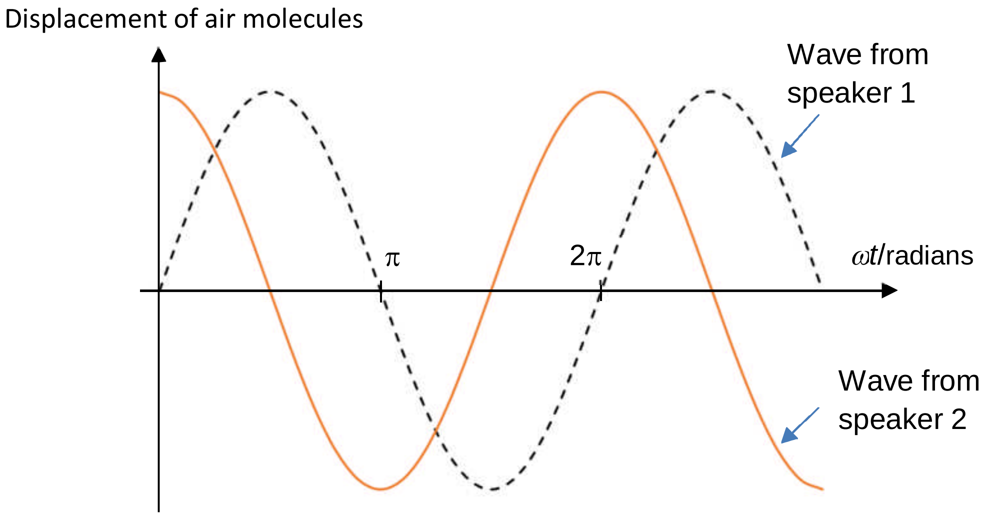


Fig. 4.1

Given that each speaker alone would still result in a sound intensity of I_o at the listener's location, deduce the resultant sound intensity that the listener hears now. Express your answer in terms of I_o.

resultant intensity = ………………………. [3]

WAVE MOTION WORKED SOLUTIONS

1 (a) $v = f\lambda$

$340 = (20 \times 10^3)\lambda$ or $340 = (80 \times 10^3)\lambda$

$\lambda = 17$ mm or $\lambda = 4.3$ mm

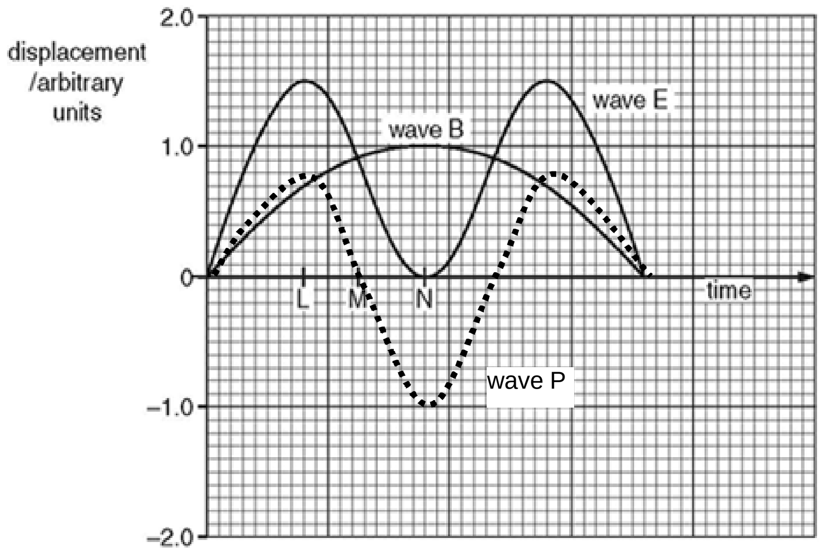
4.3 mm to 17 mm.

(b) (i) Displacement at L = 1.5 – 0.7= 0.8 (units)

Displacement at M = 0 (units) since the two curves intersect

Displacement at N = 0 – 1.0 = –1.0 (units)

(ii)



2 (a) Path difference $\delta = 11.0 - 8.0 = 3.0$ m

Phase difference = $\frac{\delta}{\lambda}.2\pi = \frac{3.0}{340/680}.2\pi = 12\pi$ radians

Accept zero radians.

(b) $A_{net} = A_o + A_o = 2A_o$ (waves arrived in phase $\Rightarrow$ constructive interference)

$I_o \propto A_o^2$ and $I_{net} \propto A_{net}^2$

Thus $I_{net} = \frac{A_{net}^2}{A_o^2} I_o = \left(\frac{2A_o}{A_o}\right)^2 I_o = 4I_o$

(c) At the listener's location, $I_A = I_B$

$$\frac{P_A}{4\pi r_A^{\ 2}} = \frac{P_B}{4\pi r_B^{\ 2}}$$

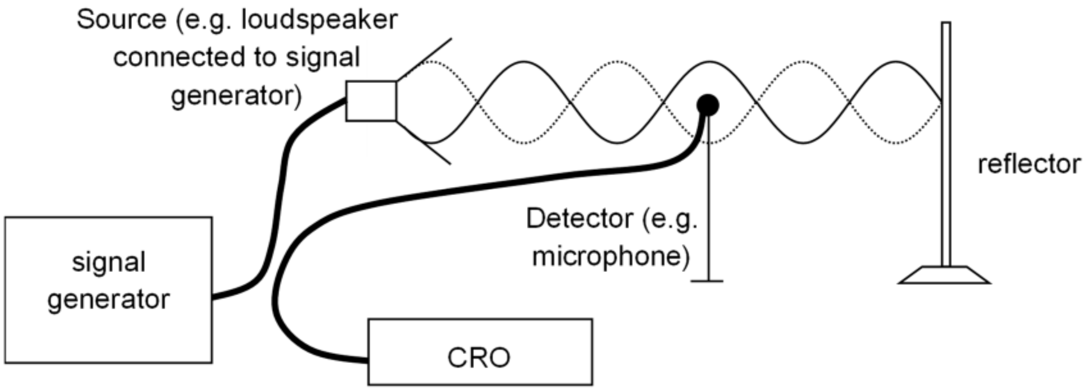
$$\frac{P_A}{P_B} = \left(\frac{r_A}{r_B}\right)^2 = \left(\frac{8.0}{11.0}\right)^2 = 0.53$$

(d) From graph, resultant wave has maximum displacement when $\omega t = \pi/4$ or 45^o

$A_{net} = A_o \sin(\pi/4) + A_o \cos(\pi/4) = \sqrt{2}\, A_o$

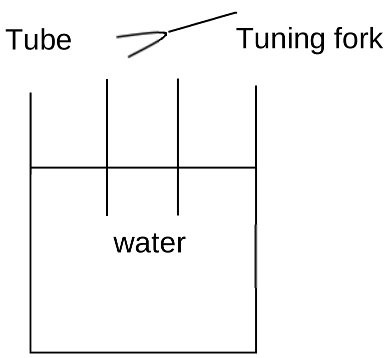
$I_{net} = 2\, I_o$

(b) Method 1



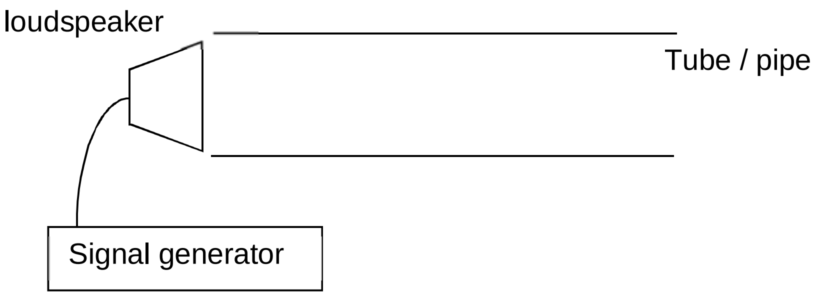
- Labelled diagram with a signal generator, loudspeaker, CRO, microphone, reflector [1 mark]
- A wave of known frequency is generated by a source, e.g. a loudspeaker connected to a signal generator.
- Shift the microphone until it registers the highest / lowest signal
- The wavelength of the wave, $\lambda = 2d$, where d is the distance between two adjacent nodes (or two adjacent antinodes).
- Using $v = f\lambda$ to calculate the speed of sound

Method 2



- Labelled diagram with a tube with 2 open ends, tuning fork and a container of water
- Use a tuning fork with known frequency.
- Shift the tube upwards until the first loud sound is heard
- The wavelength of the wave, λ = 4L where where L is the length of the tube above water surface.
- Using v= fλ to calculate the speed of sound

Method 3



- Labelled diagram with a signal generator, loudspeaker, tube / pipe
- Slowly increase the frequency of signal generator until the first loud sound is heard.
- Record of frequency of the sound from signal generator.
- λ = 2*L* where L is the length of the tube / pipe.
- Using v= fλ to calculate the speed of sound

  If the tube / pipe is closed in one end, then λ = 4*L*

7 (a) The speed of the wave is given by $v = f\lambda = \dfrac{\lambda}{T}$

$= \dfrac{0.4}{1.25} = \mathbf{0.32\,m\,s^{-1}}$

(b) The displacement time relation for point A is $\boldsymbol{y_A = -0.020\sin(\frac{2\pi}{1.25}t)}$

Or $\boldsymbol{y_A = -0.020\sin(5.03t)}$

(c) A and B are separated by distance = 2.25 λ. The phase difference is equivalent to a separation of 0.25λ.$\therefore\ \Delta\phi = \dfrac{\Delta x}{\lambda}\,\text{x}\,2\pi$

$= \dfrac{0.25\lambda}{\lambda}\,\text{x}\,2\pi = \boldsymbol{\frac{\pi}{2}}\,\mathbf{rad} = \mathbf{1.57\,rad}$

(d) As the wave spreadsout from a point source, the total energy of the wave will be distributed to and shared by the spreading ripples.

This results in a reduced amplitude in the wave away from the source.