You should try to answer on your own before seeking H-E-L-P-S.

TOPIC opening ....

Question 1

A water wave of amplitude 0.50 m is travelling in water which is 2.0 m deep, as illustrated in Fig. 2.1.

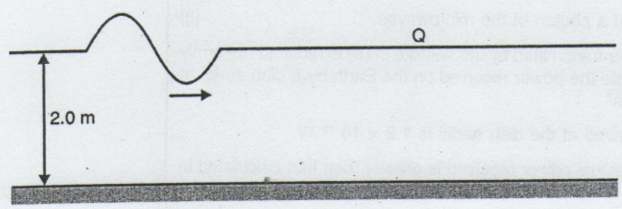


Fig. 2.1

Water waves travel with a speed v which is dependent on the depth of water h and is given by the equation

$$v\sqrt{gh}$$

Where g is the acceleration of free fall. As there is a greater depth of water beneath the crest of a water wave than beneath the trough, wave crests will travel faster than wave troughs.

(a) Determine the depth of water beneath the crest of the wave. [1]

(b) For the wave illustrated in Fig. 2.1, calculate the speed of travel of

(i) the crest,

(ii) the trough. [3]

(c) On Fig. 2.1, draw a suggested shape of the wave a little later as it passes Q. [2]

[J99/P2/Q2]

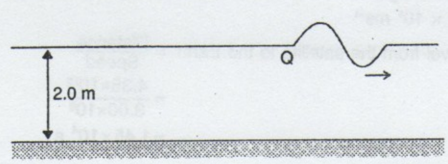
Suggested Solution:

(a) Depth of water beneath the crest of the wave = 2.0 + 0.50 = 2.5 m

(b) (i) Speed of travel of crest $= \sqrt{gh} = \sqrt{9.81 \times 2.5} = 4.95 \text{ ms}^{-1}$

(ii) Speed of travel of trough $= \sqrt{9.81 \times (2.0 - 0.5)} = 3.84 \text{ ms}^{-1}$

(c)



(c) As the wave crest travels faster than the wave trough, the wave may have a shorter wavelength as it passes Q.

Question 2

(a) Illustrate and explain the meaning of the terms *longitudinal* and *transverse* when applied to a wave. [4]

(b) A satellite passing the planet Neptune communicates with its controller on the Earth using a microwave transmitter with output power 22.0 W and wavelength 79 600 μm. Neptune is 4.35×10^{12} m from the Earth at the time when the communication takes place.

(i) State whether the microwaves are progressive or stationary.

(ii) State whether the microwaves are longitudinal or transverse.

(iii) Calculate the time taken for a signal to travel from the satellite to the Earth.

(iv) Calculate the energy of a photon of the microwaves. [8]

(c) (i) Assuming that the power transmitted by the satellite in **(b)** is radiated uniformly in all directions, calculate the power received on the Earth by a dish aerial of effective area of 260 m^2.

(ii) The actual power received at the dish aerial is 1.2×10^{-15} W.

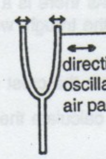
1. Suggest why the actual power received is greater than that calculated in (c)(i).

2. Calculate the actual rate at which photons of microwaves arrive at the dish aerial. [8]

[D02/P3/Q6]

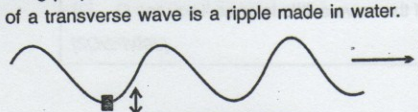
Suggested Solution:

(a) The term *'longitudinal'* when applied to a wave refers to the oscillation of the particles in the wave being parallel to the direction of travel of the wave.



An example of a longitudinal wave is a sound wave travelling in air.

The term *'transverse'* when applied to a wave refers to the oscillation of the particles in the wave being perpendicular to the direction of travel of the wave.
An example of a transverse wave is a ripple made in water.



(b) (i) Progressive

(ii) Transverse

(iii) Speed of microwaves = Speed of light
$= 3.00 \times 10^8\ ms^{-1}$

Time taken for a signal to travel from the satellite to the Earth $= \dfrac{\text{Distance}}{\text{Speed}}$

$= \dfrac{4.35 \times 10^{12}}{3.00 \times 10^8}$

$= 1.45 \times 10^4$ s

(b) (i) The microwaves have to travel from the transmitter to the controller.

(ii) All waves in the electromagnetic spectrum are transverse.

(iv) Energy of a photon of the microwaves,

$E = hf$

$= 6.63 \times 10^{-34} \times \dfrac{3.0 \times 10^8}{79600 \times 10^{-6}} = 2.5 \times 10^{-24}$ J

(b) (iv) 1μm = 10^{-6} m

(c) (i) Power received by the dish $= \dfrac{\text{Dish area}}{\text{Surface area over all space}} \times \text{Power output}$

$= \dfrac{260}{4\pi(4.35\times10^{12})^2} \times 22.0$

$= 2.41\times10^{-23}$ W

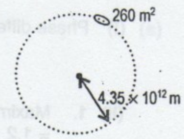
(ii) 1. Instead of transmitting over all-space, the transmitter could have been directed at the dish. The power transmitted would then be concentrated in a cone (see diagram in 'Learning Corner') rather than radiated uniformly in all directions.

2. Power received = Rate of arrival of photons at the aerial × Energy of each photon

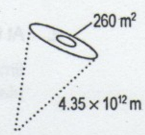
$\therefore$ Actual rate of arrival $= \dfrac{1.2\times10^{-15}}{2.5\times10^{-24}} = 4.8\times10^{8}\ \text{s}^{-1}$

Learning CORNER

(c)(i)



(ii)



Question 3

Fig. 4.1 shows a displacement-distance graph for two sound waves **A** and **B**, of the same frequency and amplitude. Wave **A** is travelling to the right and wave **B** is travelling to the left.

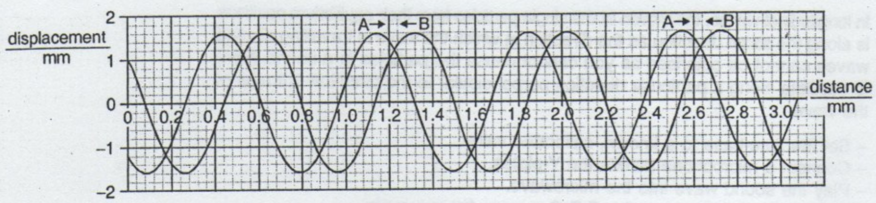


Fig. 4.1

(a) (i) From the graph, deduce the phase difference between the two waves at the instant shown. [1]

(ii) The period of each wave is T. Determine the maximum displacement of the resultant of the two waves

1. at the instant shown,

2. at the instant shown $+\frac{1}{8}T$,

3. at the instant shown $+\frac{3}{8}T$. [5]

(b) Describe features of the resultant wave set up by the two waves travelling in opposite directions. [3]

(c) Fig. 4.1 has the disadvantage that it makes the sound wave appear to be a transverse wave, when it is not.

(i) What type of wave is sound? [1]

(ii) Explain why sound waves cannot be polarised. [2]

(d) Describe how a cathode-ray oscilloscope (c.r.o.) may be used to determine the frequency of a sound wave. [5]

(e) The waves in Fig. 4.1 have a frequency of 484 Hz. Deduce their speed to **three** significant figures. [3]

[D03/P3/Q4]

Suggested Solution:

(a) (i) Phase difference $= \frac{1}{4} \times 2\pi$ rad

$= \frac{\pi}{2}$ rad

(a) (i) Wave A is at its peak when wave B is at 0 displacement. Hence phase difference is $\frac{1}{4} \times 2\pi$ rad.

(ii) 1. Maximum displacement of the resultant of the 2 waves at the instant shown $= 1.2 \times 2 = 2.4$ mm

2. At the instant shown $+\frac{1}{8}T$, one wave would have moved $\frac{2}{8}T = \frac{1}{4}T$ period of time relative to the other. The phase difference would be π rad. Maximum displacement of the resultant of the two waves = 0 mm.

3. At the instant shown $+\frac{3}{8}T$, one wave would have moved $2 \times \frac{3}{8}T = \frac{6}{8}T = \frac{3}{4}T$ period of time relative to other. The phase difference would be 0 rad. Maximum displacement of the resultant of the two waves $= 1.6 \times 2 = 3.2$ mm.

(b) The resultant wave set up by the two waves travelling in opposite directions will be a stationary wave. Hence, it will have points where the resultant displacement is always zero (nodes).

(c) (i) Longitudinal

(ii) In longitudinal waves, the motion of the single particles from their equilibrium positions is along the same direction as the direction in which the wave is travelling. Sound waves cannot be polarised as you cannot cause the particles in a sound wave to oscillate along a particular direction perpendicular to the direction of travel of the wave.

(d)
- Set the time-base to a known, calibrated value.
- Connect a microphone across the Y-plates.
- Play the sound wave into the microwave.
- Measure the distance on the C.R.O. screen for one cycle.
- Calculate the period of the wave using the time-base.
- Calculate the frequency $= \left(\frac{1}{\text{period}}\right)$ of the wave.

(e) $\lambda = \frac{1.84 - 0.08}{2.5} = 0.704$ m

(e) Deduce λ from Fig. 4.1.

Speed $= f\lambda$

$= 484 \times 0.704$ m

$= 341$ ms^{-1} (3 S.F.)

Question 4

(a) A string is stretched between two points. When the string is plucked, a stationary wave is produced on the string, as illustrated in Fig. 4.1.

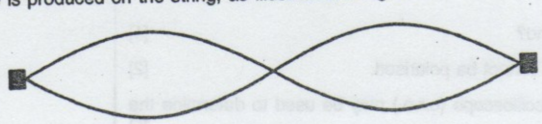


Fig. 4.1

The stationary wave has frequency f and wavelength λ.

(i) 1. State, in terms of λ, the minimum separation of two points that have zero amplitude of vibration.

separation = ... [1]

2. State the phase angle between the vibrations of points on the string situated at adjacent antinodes.

phase angle = ...° [1]

(ii) The speed v of a progressive wave is given by the expression

$$v = f\lambda.$$

A stationary wave does not have a speed. By reference to the formation of a stationary wave, explain the significance of the product $f\lambda$ for a stationary wave. [3]

(b) Fig. 4.2 shows some energy levels for the hydrogen atom.

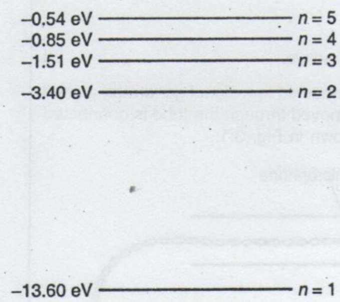


Fig. 4.2

A line emission spectrum is produced when electrons make transitions down to the $n = 1$ state.

(i) Show, using a suitable calculation, that this line spectrum is **not** within the visible region of the electromagnetic spectrum. [5]

(ii) State the region in which this line spectrum is to be found.

....[1]

[D04/P2/Q4]

Suggested Solution:

(a) (i) 1. separation $= \frac{1}{2}\lambda$

2. phase angle = 180°

(ii) A stationary wave can be set up in a stretched string by connecting one end of the string to an immoveable point (node) and the other end to a vibrating blade (antinode). When the frequency of the blade equals one of the normal frequencies of the string, standing waves will be produced.

$f\lambda$ refers to the velocity of the wave which can give rise to the standing wave.

(b) (i) Greatest frequency line is produced when the electron makes a transition from $n = 5$ to $n = 1$.

$$E = hf$$

$$f = \frac{E}{h}$$

$$= \frac{(-0.54 + 13.60) \times 1.60 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= 3.15 \times 10^{15} \text{ Hz}$$

Lowest frequency is produced when the electron makes a transition from $n = 2$ to $n = 1$.

$$f = \frac{E}{h}$$

$$= \frac{(-3.40 + 13.60) \times 1.60 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= 2.46 \times 10^{15} \text{ Hz}$$

Since the frequency of electromagnetic waves within the visible region ranges from about 4×10^{14} Hz (red) to about 8×10^{14} Hz (violet), the line spectrum in question does not fall within the visible region.

(ii) Ultraviolet

Question 5

(a) Explain what is meant by the term *stationary wave.* [3]

(b) A long glass tube has small loudspeakers, connected to a signal generator, placed at one end. A small microphone that can be moved through the tube is connected to a cathode-ray oscilloscope (CRO), as shown in Fig. 3.1.

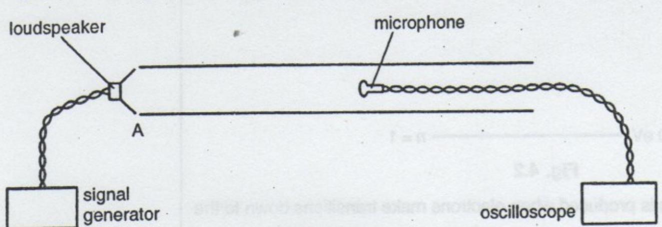


Fig. 3.1

For some frequencies of the signal generator, the microphone detects large-amplitude signals at certain positions and low-amplitude signals at other positions. The results obtained are given in the table of Fig. 3.2.

frequency / Hz	distance of microphone from the loudspeaker for maximum amplitude signal / mm						
270	102	724	1348				
405	82	499	913	1332			
540	62	375	685	1000	1310		
675	52	302	552	800	1050	1300	
810	47	253	462	670	880	1088	1296

Fig. 3.2

(i) Using the distance in the table, deduce the wavelength of the sound at each frequency. Sow your working. [4]

(ii) Use your values from **(i)** to determine five values for the speed of sound in the tube. [3]

(iii) Calculate the average value for the speed of sound. [1]

(iv) Suggest a value for the uncertainty in the speed of sound you have found in **(iii)**. Explain how you obtained this value. [2]

(c) Microphones are devices that detect variations of air pressure. By describing the movement of molecules in a stationary sound wave, explain where the air pressure varies most and where it varies least. [4]

(d) Suggest how stationary electromagnetic waves might be set up. [3]

[N05/P3/Q3]

Suggested Solution:

(a) Stationary waves are formed when two progressive waves having same time period and speed but travelling in opposite directions are super-posed.

(b) (i)&(ii)

frequency / Hz	distance / mm	speed / ms^{-1}
270	1246	336
405	831	337
540	623	336
675	500	338
810	415	336

To find distance, use the 3rd value minus 1st value under distance column for each frequency.

E.g. for 270 Hz : wavelength = 1348 − 102 = 1246 mm

(iii) Average speed $= \frac{1}{5}(336 + 337 + 336 + 338 + 336) = 337\ ms^{-1}$

(iv) Uncertainty is $\pm 1\ ms^{-1}$, as the range of the values is from 336 to 338 ms^{-1}. It is obtained by halving the difference of the maximum and minimum of the speed calculated.

(c) Nodes (zero displacement) and antinodes (maximum displacement) occurs in stationary waves.

Air pressure is highest near the nodes as air molecules are closer and varies least.

Air pressure is lowest near the antinodes as air molecules are further apart and varies most.

(d) All electromagnetic waves have the same speed.

A stationary wave can be formed by the emitting wave and reflected wave off a surface along the same straight line.

Question 6

(a) Give reasons for the following.

(i) Sound waves and water waves can go round corners but light waves seem to travel only in straight lines. [2]

(ii) Sound waves cannot be polarised but radio waves can be polarised. [1]

(iii) Fig. 4.1 represents a stationary sound wave in a pipe. This figure looks like a transverse wave although sound waves are longitudinal waves. [2]

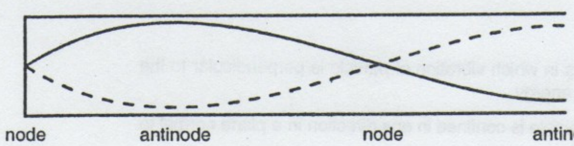


Fig. 4.1

(iv) A small radio receiver situated between a radio transmitter and a large reflector will not detect a signal in certain areas. [2]

[N06/P3/Q4(a)]

Suggested Solution:

(a) **(i)** Wavelengths of light waves have small wavelengths compared to the obstacles and hence does not diffract.

(ii) Sound waves are longitudinal waves.

(iii) This is due to the interference of two sound waves which results in the same phase of wave between nodes and π radians out of phase to adjacent waves.

(iv) This is because of the stationary waves set up by the radio transmitter and reflector. No signals will be received for places of nodes for stationary waves.

Question 7

Light reflected from the surface of smooth water may be described as a polarised transverse wave.

(a) By reference to the direction of propagation of energy, explain what is meant by

(i) a *transverse wave*, [1]

(ii) *polarisation*. [1]

(b) A glass tube, closed at one end, has fine dust sprinkled along its length. A sound source is placed near the open end of the tube, as shown in Fig. 5.1.

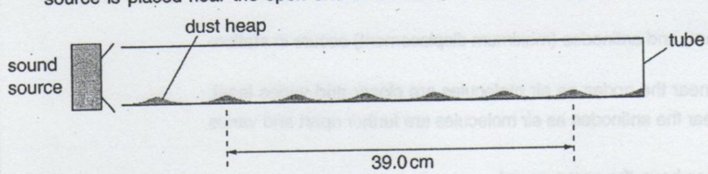


Fig. 5.1

The frequency of the sound emitted by the source is varied and, at one frequency, the dust forms small heaps in the tube.

(i) Explain, by reference to the properties of stationary waves, why the heaps of dust are formed. [3]

(ii) One frequency at which heaps are formed is 2.14 kHz.

The distance between six heaps, as shown in Fig. 5.1, is 39.0 cm.

Calculate the speed of sound in the tube. [3]

(c) The wave in the tube is a stationary wave. Explain, by reference to the formation of a stationary wave, what is meant by the speed calculated in **(b)(ii)**. [3]

[J07/P2/Q5]

Suggested Solution:

(a) **(i)** *A transverse wave:* Waves in which vibration of particle is perpendicular to the direction of propagation of energy.

(ii) *polarisation:* Vibration of particle is confined in one direction in a plane normal to the direction of propagation.

(b) **(i)** Antinodes are points on stationary waves where the amplitude of vibration is maximum. At nodes displacement is zero and heap are formed. So dust is pushed to settle down at the nodes by the Antinodes.

(b) (i) Energy of the antinode push the dust particles to settle down at nodes.

(ii) $2.5\lambda = 39$ cm

$\lambda = \frac{39}{2.5} = 15.6$ cm

$v = f\lambda$

$= (2.14\times10^3)(15.6\times10^{-2}) = 334$

$\therefore$ speed $= 334$ ms^{-1}

(ii) Distance between 6 heaps = 2.5λ.

(c) Stationary waves are formed due to super-position of two waves having same speed but travelling in opposite directions. It's speed is same as that of either incident or reflected wave.

Question 8

(a) State what is meant by

(i) the *frequency* of a progressive wave, [2]

(ii) the *speed* of a progressive wave. [1]

(b) One end of a long string is attached to an oscillator. The string passes over a frictionless pulley and is kept taut by means of a weight, as shown in Fig. 5.1.

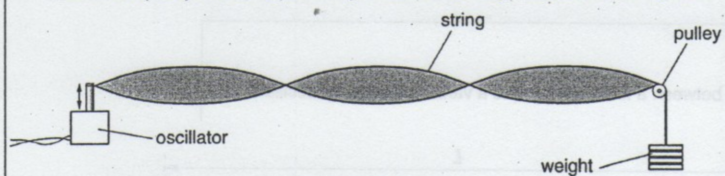


Fig. 5.1

The frequency of oscillation is varied and, at one value of frequency, the wave formed on the string is as shown in Fig. 5.1.

(i) Explain why the wave is said to be a *stationary* wave. [1]

(ii) State what is meant by an *antinode*. [1]

(iii) On Fig. 5.1, label the antinodes with the letter A. [1]

(c) A weight of 4.00 N is hung from the string in **(b)** and the frequency of oscillation is adjusted until a stationary wave is formed on the string. The separation of the antinodes on the string is 17.8 cm for a frequency of 125 Hz.
The speed v of waves on a string is given by the expression

$$v = \sqrt{\frac{T}{m}},$$

where T is the tension in the string and m is its mass per unit length.
Determine the mass per unit length of the string. [5]

[J08/P2/Q5]

Suggested Solution:

(a) (i) Number of oscillations of the source per unit time.

(ii) Distance travelled by a progressive wave per unit time.

(b) (i) Because no energy is transferred along the wave in stationary waves.

(ii) Position along the stationary waves where amplitude of vibration is maximum.

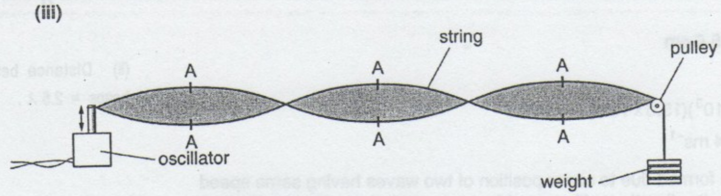
(a) (i) Number of oscillations of a particle on the wave per unit time.

(ii) • Speed at which energy is transferred
• $v = f\lambda$ is a derived formula and can not be used to define speed of a wave.

(b) (i) Zero energy is transferred due to static positions of nodes.

(ii) Position between two successive nodes having maximum amplitude is antinode.

(iii)



(c)

$$f\lambda = \sqrt{\frac{W}{m}}$$

$$(125)(2\times 17.8\times 10^{-2}) = \sqrt{\frac{400}{m}}$$

$$m = \frac{4.00}{(44.5)^2} \Rightarrow m = 2.02\times 10^{-3}$$

$\therefore$ mass per unit length $= 2.02\times 10^{-3}$ kgm^{-1}

(c) • Distance between two successive nodes $= \frac{\lambda}{2}$

$\lambda = 2(17.8) = 35.6$ cm

• Tension in the string is equal to the weight of the suspended mass.

Question 9

A uniform string is held between a fixed point P and a variable-frequency oscillator, as shown in Fig. 5.1.

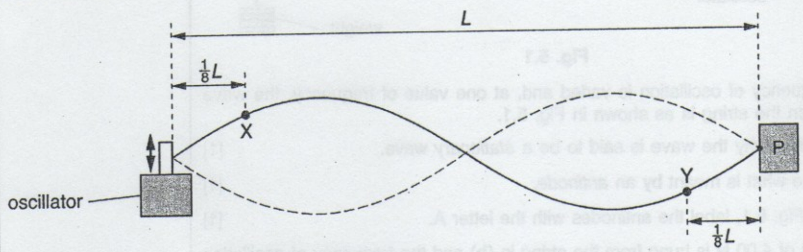


Fig. 5.1

The distance between point P and the oscillator is L.

The frequency of the oscillator is adjusted so that the stationary wave shown in Fig. 5.1 is formed.

Points X and Y are two points on the string.

Point X is a distance $\frac{1}{8}L$ from the end of the string attached to the oscillator. It vibrates with frequency f and amplitude A.

Point Y is a distance $\frac{1}{8}L$ from the end P of the string.

(a) For the vibrations of point Y, state

(i) the frequency (in terms of f), [1]

(ii) the amplitude (in terms of A). [1]

(b) State the phase difference between the vibrations of point X and point Y. [1]

(c) (i) State, in terms of f and L, the speed of the wave on the string. [1]

(ii) The wave on the string is a stationary wave.

Explain, by reference to the formation of a stationary wave, what is meant by the speed stated in (i). [3]

[N09/P22/Q5]

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Suggested Solution:

(a) (i) frequency = f

(ii) amplitude = A

(b) phase difference = 180°

(c) (i) speed = $v = fL$

(ii) Stationary waves are produced when incident wave and reflected progressive wave from P moving with same speed but travelling in opposite direction meet. The speed of stationary wave is same as that of incident or reflected wave.

Learning CORNER

(a) (ii) Unlike that of an (unattenuated) progressive wave, the amplitude of a stationary wave depends upon position. It ranges from zero at the nodes to $2A$ at the antinodes, where 'A' is the amplitude of either one of the progressive wave that have combined to produce the stationary wave.

(b) { π radian }
The particles on either side of a node are 180° out of phase with each other.

(c) (i) Here $\lambda = L$

$v = f\lambda$

$v = fL$