THE PR:IME! PACKAGE PART 3

Mechanics 3 and Waves
(Oscillation, Wave Motion, Superposition)

MCQ

1 Which of the following statements about the acceleration of a particle undergoing simple harmonic motion is true?

A It varies linearly with the frequency of oscillation.

B It is always in the opposite to the velocity of the particle.

C It has the smallest magnitude when the speed of the particle is the greatest.

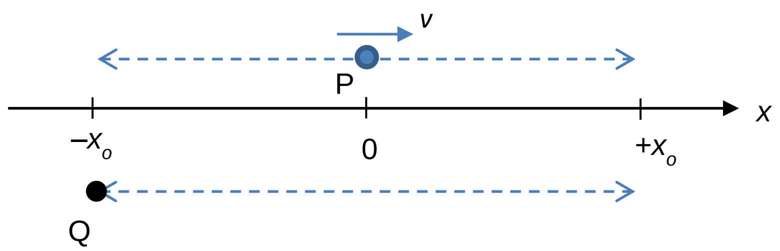
D Its magnitude is the minimum when the displacement of the particle is a maximum.

[RJC 2012]

C

Using $a = -\omega^2 x$, acceleration varies linearly with the square of frequency. Magnitude of acceleration is maximum when displacement is a maximum. If acceleration is a sine curve, velocity will be a negative cosine curve – B is not always true. At eqm, when speed is maximum, acceleration is zero.

2 Two particles, P and Q, are performing simple harmonic motions about point 0 along the x-direction with the same amplitude, x_o. The period of P's oscillation is T, while that of Q is unknown. At a certain instant as shown, P is at its equilibrium position and moving in the positive x-direction, Q is at $-x_o$.



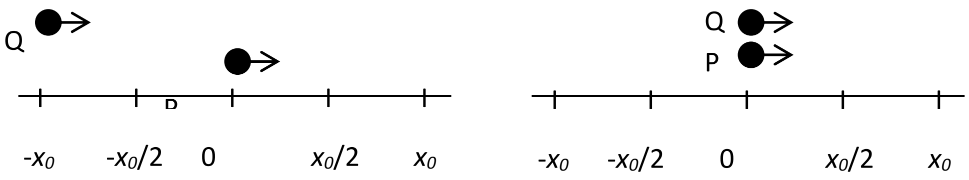
At time 2T later, it is observed that both P and Q have the same displacement and velocity. What is a possible period of oscillation for particle Q, in terms of T?

A (3/4) T **B** (4/5) T **C** (8/9) T **D** (5/4) T

[HCI 2013]

C

Initial: Final:

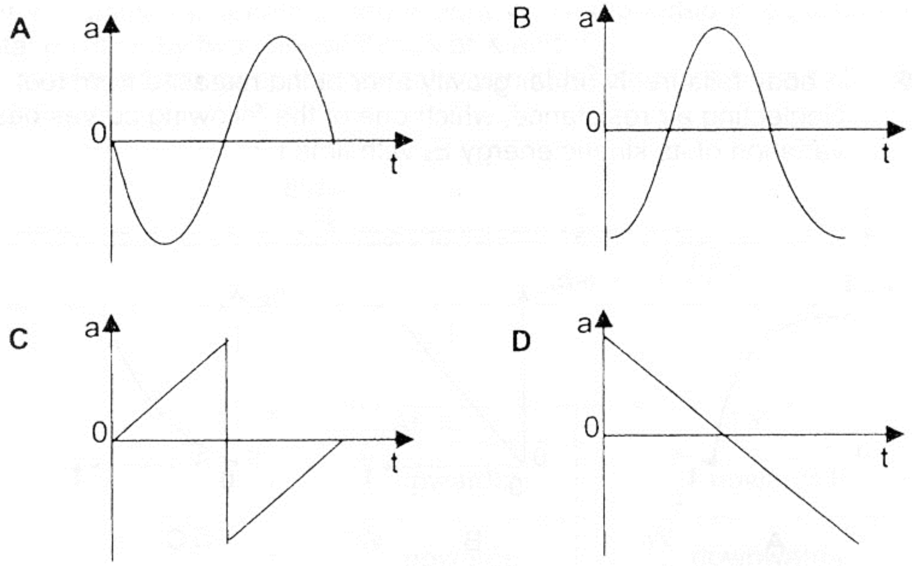


Time 2*T* later, P will have completed 2 cycles and returned to same position whereas B would have completed 2 & 1/4 cycles in order to catch up.

$$2\frac{1}{4}T_Q = 2T \Rightarrow T_Q = \frac{8}{9}T$$

3 The bob of a simple pendulum moves through its equilibrium position at time t = 0.

Which of the following graphs A to D best shows the variations of the acceleration a of the bob with time t?



[MJC 2012]

A

The displacement of the pendulum bob varies sinusoidal with time. The variation of its acceleration with time will be 180^0 out of phase with its displacement. Use trigo to show.

4 An object placed on a horizontal platform is vibrating vertically in simple harmonic motion with a frequency of 2.0 Hz.

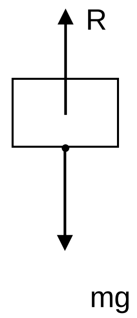
The amplitude of vibration of the platform is gradually increased from zero. At one particular amplitude, the object is seen to lose contact with the platform.

What is the amplitude of the oscillation when this occurs?

A 3.9 cm **B** 6.2 cm **C** 7.8 cm **D** 12.4 cm

[AJC 2013]

B



ma = mg – R

Object will remain in contact when R is greater than 0.

Object will lose contact when R = 0,

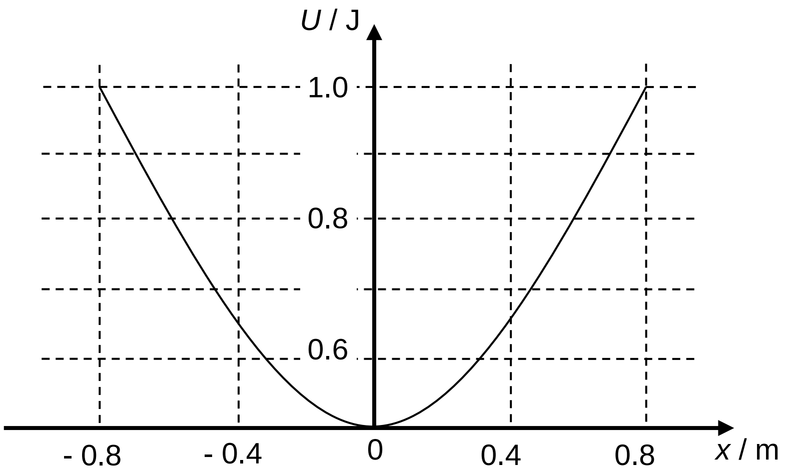
ma = mg

For SHM,

$a = \omega^2 x_o = (2\pi f)^2 x_o = g$

$x_o = \dfrac{g}{(2\pi f)^2} = \dfrac{9.81}{(2\pi(2.0))^2} = 0.062$ m

5 A particle of mass 5.0 kg moves with simple harmonic motion and the variation with position *x* of its potential energy *U* is shown below.



What is the period of oscillation of the mass?

A 7.9 s **B** 8.8 s **C** 11 s **D** 20 s

[AJC 2013]

A

$KE_{max} = U_{max} = 1.0$

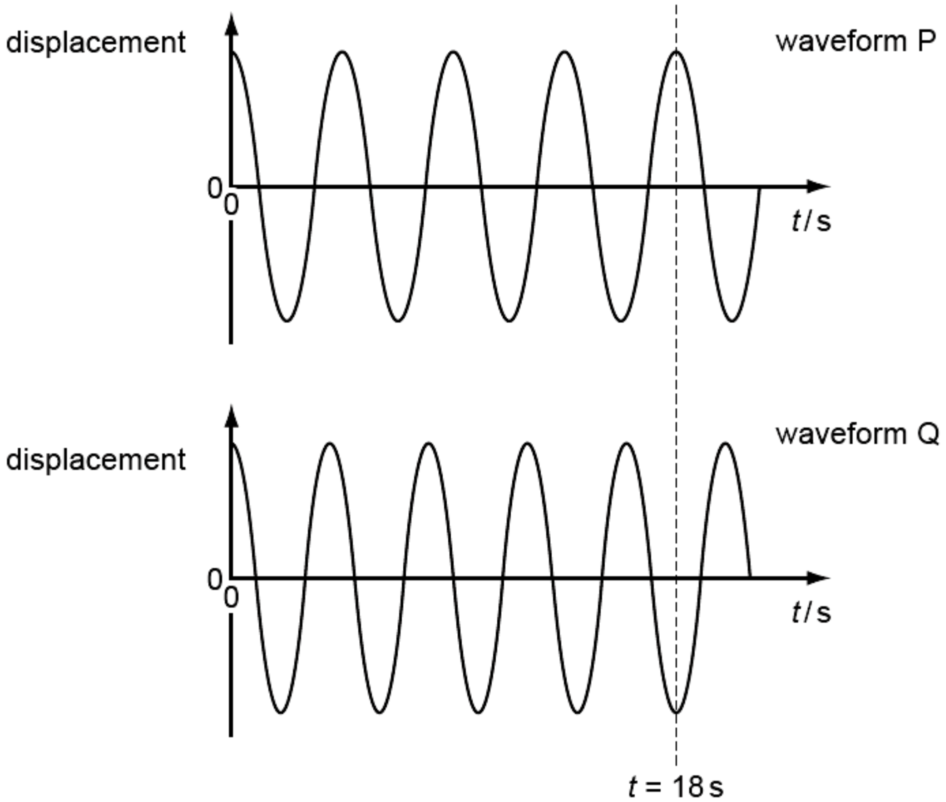
$\frac{1}{2} m v_{max}^2 = 1.0$

$v_{max} = 0.632$

$v_{max} = \omega x_o = \dfrac{2\pi}{T} x_o$

$T = \dfrac{2\pi \times 0.8}{0.632} = 7.9$ s

6 The figure below shows two sinusoidal waveforms.



At time t = 0 the waves are in phase. At time t = 18 s, the phase difference between the two oscillations is π rad.

At which time is the phase difference between the two oscillations ⅛ of a cycle?

A 4.0 s **B** 4.5 s **C** 8.0 s **D** 9.0 s

[AJC 2013]

B
Phase difference of π rad corresponds to 18 s
1/8 of a cycle corresponds to a phase difference of π/4.
→hence phase difference of π/4 rad corresponds to 18/4 = 4.5 s

7 A particle is oscillating with simple harmonic motion described by the displacement equation x = 5 sin (20 π t)

How long does it take the particle to travel from its position of maximum displacement to its equilibrium position?

A $\frac{1}{40}$ s **B** $\frac{1}{20}$ s **C** $\frac{1}{10}$ s **D** $\frac{1}{5}$ s

[MI 2013]

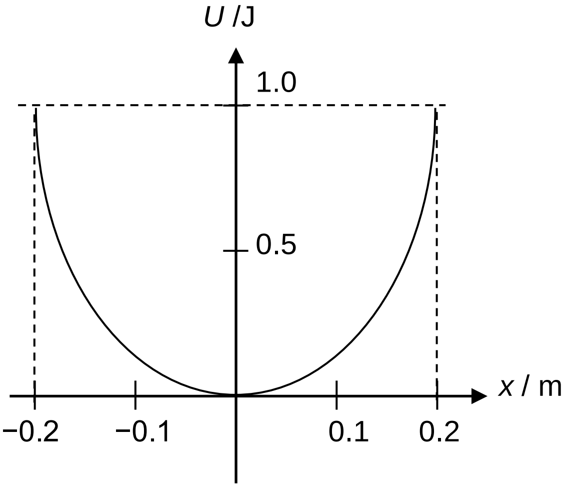
A

$$x = x_0 \sin \omega t$$

$$\therefore \omega = 20\pi$$

$$\frac{T}{4} = \frac{1}{4}\left(\frac{2\pi}{20\pi}\right) = \frac{1}{40} s$$

8 A particle of mass 4 kg moves with simple harmonic motion and its potential energy U varies with position x as shown in the diagram.



What is the period of oscillation of the mass?

A 0.56 s **B** 1.00 s **C** 1.78 s **D** 2.50 s

[MI 2013]

C

$$U = \frac{1}{2} m\omega^2 x^2$$

$$1.0 = \frac{1}{2}(4)\omega^2 (0.2)^2 \Rightarrow \omega = 3.536$$

$$\omega = \frac{2\pi}{T} = 3.536 \Rightarrow T = 1.78\,\text{s}$$

9 A particle of mass 150 g moves with simple harmonic motion with an amplitude of 2.5 cm. At a displacement of 1.0 cm from the equilibrium point, its kinetic energy is 0.62 J.

What is its natural frequency of oscillation?

A 18 Hz **B** 20 Hz **C** 22 Hz **D** 24 Hz

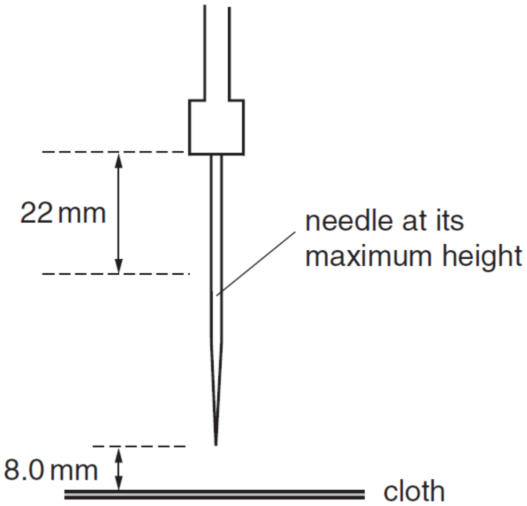
[RVHS 2013]

B

The velocity of the oscillating particle, $v = \omega\sqrt{(x_o^2 - x^2)}$

Its k.e., $E_k = ½\, m\, v^2 = ½\, m\, \omega^2 (x_o^2 - x^2)$
i.e. $0.62 = ½\, m\, \omega^2 (x_o^2 - x^2)$
$= ½\,(150 \times 10^{-3})(2\pi f)^2(0.025^2 - 0.010^2)$
Thus, $f = 20$ Hz

10 The needle of a sewing machine is made to oscillate vertically through a total distance of 22 mm, as shown below.



The oscillation is simple harmonic with a frequency of 4.5 Hz. The cloth that is being sewn is positioned 8.0 mm below the point of the needle when the needle is at its maximum height.

What is the speed of the needle as its tip just touches the cloth?

A 0.00317 m s^{-1} **B** 0.0848 m s^{-1} **C** 0.226 m s^{-1} **D** 0.299 m s^{-1}

[MJC 2013]

D

Amplitude, x_0 = 22/2 = 11 mm

When the point of needle is about to move downwards through the cloth, displacement of needle from origin is 3 mm.

$v = \omega\sqrt{x_o^2 - x^2} = (2\pi (4.5))(\sqrt{(11 \times 10^{-3})^2 - (3 \times 10^{-3})^2} = 0.299\ ms^{-1}$

11 A particle of mass 5.0 × 10^{-3} kg performing simple harmonic motion of amplitude 150 mm takes 47 s to make 50 oscillations.

What is the maximum kinetic energy of the particle?

A 2.0 × 10^{-3} J **B** 2.5 × 10^{-3} J **C** 3.9 × 10^{-3} J **D** 5.0 × 10^{-3} J

[MJC 2013]

B

Frequency = 50/47 Hz

$KE_{max} = \frac{1}{2}m(\omega x_0)^2 = \frac{1}{2}m(2\pi f x_0)^2 = (0.5)(5.0 \times 10^{-3})(2\pi (50/47)(150 \times 10^{-3}))^2 = 2.5 \times 10^{-3}$ J

12 An object is moving in simple harmonic motion with amplitude A.
What is its distance from the equilibrium position in terms of A when its kinetic energy is equal to its potential energy?

A $\frac{A}{3}$ **B** $\frac{A}{2}$ **C** $\frac{A\sqrt{2}}{2}$ **D** $\frac{A\sqrt{3}}{2}$

[JJC 2012]

C: Let the displacement of the SHM be represented by

$$x = A\sin\omega t$$

Thus, the velocity is given by

$$v = A\omega\cos\omega t$$

and the kinetic energy is given by

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}mA^2\omega^2\cos^2\omega t$$

Now, $KE_{\max} = PE_{\max} = TE = \frac{1}{2}mA^2\omega^2$

The potential energy is given by

$$PE = TE - KE = \frac{1}{2}mA^2\omega^2 - \frac{1}{2}mA^2\omega^2\cos^2\omega t = \frac{1}{2}mA^2\omega^2\sin^2\omega t$$

When PE=KE,

$$\frac{1}{2}mA^2\omega^2\cos^2\omega t = \frac{1}{2}mA^2\omega^2\sin^2\omega t$$

$$\tan^2\omega t = 1$$

$\omega t = \frac{\pi}{4}$ and $x = A\sin\frac{\pi}{4} = \frac{A\sqrt{2}}{2}$

$$KE = PE$$

$$A^2 - x^2 = x^2$$

OR $A^2 = 2x^2$

$$x = \frac{A\sqrt{2}}{2}$$

all the particles in one segment are in phase.

13 A particle of mass *m* performs simple harmonic motion with period *T* and amplitude x_o about a fixed point O. The total energy of the particle is *E*. What is the change in kinetic energy, in terms of *E*, of the particle as it moves from the extreme position to a point $x_o/2$ from O?

A $E/4$ **B** $E/2$ **C** $E/\sqrt{2}$ **D** $3E/4$

[HCI 2013]

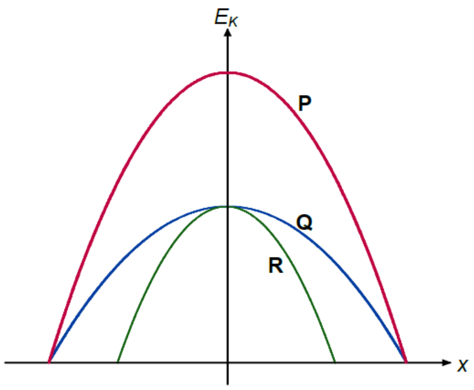
D

$$\Delta KE = KE_{final} - KE_{initial}$$

$$\Delta KE = \tfrac{1}{2}m\omega^2(x_0{}^2 - x^2) - 0$$

$$\Delta KE = \tfrac{1}{2}m\omega^2(x_0{}^2 - \tfrac{1}{4}x_0{}^2) = \tfrac{3}{4}(\tfrac{1}{2}m\omega^2 x_0{}^2) = \tfrac{3}{4}E$$

14 The figure below shows plots of kinetic energy EK vs displacement x for three harmonic oscillations of the same mass.



Which of the following statements about the oscillators is correct?

A The maximum potential energy of oscillator Q is greater than oscillator R.

B The maximum linear momentum of oscillator P is the largest.

C The angular frequency of oscillator Q is the largest.

D The angular frequency of oscillator R is smaller than oscillator Q.

[IJC 2013]

B

A The maximum potential energy of oscillator Q is greater than oscillator R.

$K.E._{max} = P.E._{max}$

$K.E._{max,Q} = K.E._{max,R}$

$P.E._{max,Q} = P.E._{max,R}$

B The maximum linear momentum of oscillator P is the largest.

$K.E._{max,P} > K.E._{max,R}$ & $K.E._{max,Q}$

$K.E._{max,P} = \frac{1}{2}mv^2$

Since they have the same mass, $V_{max,P}$ is the largest.

C The angular frequency of oscillator Q is the largest.

$K.E._{max,P} > K.E._{max,Q}$

$K.E._{max,Q} = \frac{1}{2}mv^2 = \frac{1}{2}m_Q{\omega_Q}^2{x_{0,Q}}^2$

$K.E._{max,P} = \frac{1}{2}mv^2 = \frac{1}{2}m_P{\omega_P}^2{x_{0,P}}^2$

$$\frac{1}{2}m_P{\omega_P}^2{x_{0,P}}^2 > \frac{1}{2}m_Q{\omega_Q}^2{x_{0,Q}}^2$$

Since they have the same mass and the same amplitude, X_0

$${\omega_P}^2 > {\omega_Q}^2$$

D The angular frequency of oscillator R is smaller than oscillator Q.

$K.E._{max,R} = K.E._{max,Q}$

$K.E._{max,Q} = \frac{1}{2}mv^2 = \frac{1}{2}m_Q{\omega_Q}^2{x_{0,Q}}^2$

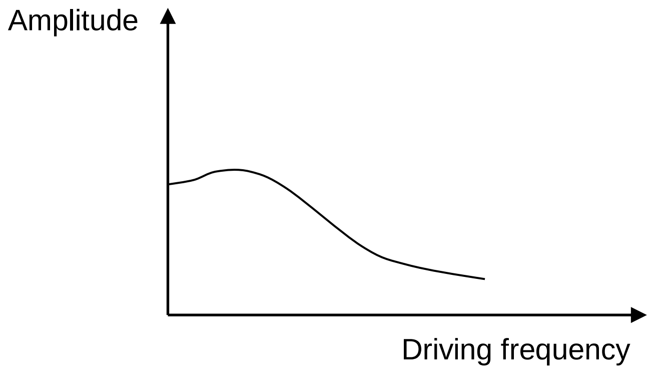
$K.E._{max,R} = \frac{1}{2}mv^2 = \frac{1}{2}m_R{\omega_R}^2{x_{0,R}}^2$

$$\frac{1}{2}m_R{\omega_R}^2{x_{0,R}}^2 = \frac{1}{2}m_Q{\omega_Q}^2{x_{0,Q}}^2$$

Since they have the same mass and $X_{0,R} < X_{0,Q}$

${\omega_R}^2 > {\omega_Q}^2$

15 An oscillatory system is made to oscillate by a driving system. The graph below shows how the amplitude of the oscillatory system varies with the frequency of the driving system.



Which of the following statements must be true of the oscillatory system?

A The graph shows that the oscillatory system is experiencing critical damping.

B The oscillatory system can only complete one oscillation before coming to rest.

C At resonance, the energy supplied to the oscillatory system equals to the energy lost by it.

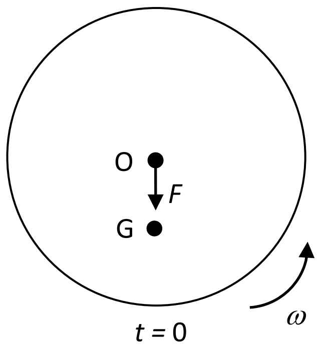
D At resonance, the amplitude of the oscillatory system decreases with time.

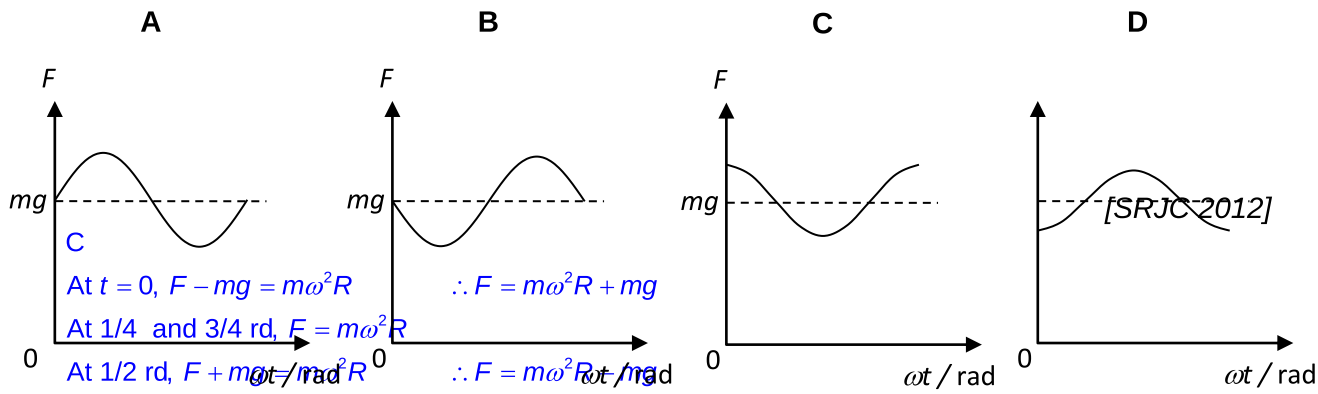
[IJC 2013]

C

16 A wheel, mass m, of which the centre of mass G is not at its centre is mounted on bearings with its axle horizontal and it rotates about its centre O with constant angular velocity ω as shown below.

Which one of the following graphs best illustrates the variation of the force F on the bearings as the wheel rotates through one revolution?





C

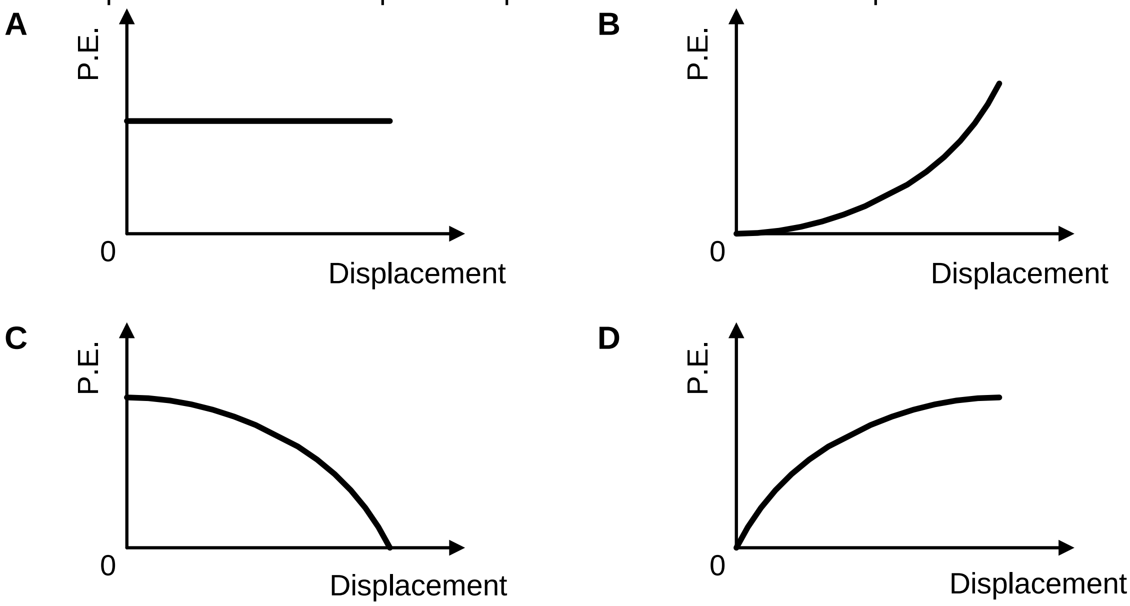
At $t = 0$, $F - mg = m\omega^2 R$ $\therefore F = m\omega^2 R + mg$

At 1/4 and 3/4 rd, $F = m\omega^2 R$

At 1/2 rd, $F + mg = m\omega^2 R$ $\therefore F = m\omega^2 R - mg$

[SRJC 2012]

17 Which one of the following graphs best represents the variation of potential energy (P.E.) with displacement from its equilibrium position of a mechanical simple harmonic motion?



[JJC 2013]

B

The P.E against displacement graph will follow U shape graph as P.E= $\frac{1}{2}m\omega^2x^2$

18 Which of the following is not an example of resonance?

A Sound made by guitar strings.

B Radio tuning to pick up a particular frequency from a radio station.

C Car suspension system.

D Pushing someone on a swing.

[JJC 2013]

C

19 Which of the following statements is correct for an object undergoing a very lightly damped oscillation?

A The period of oscillation increases over time.

B The total energy of object decrease exponentially with time.

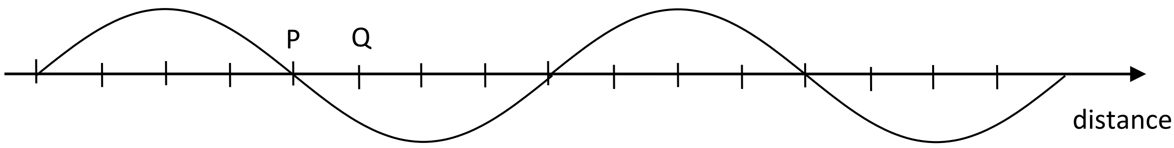
C The amplitude of the oscillation is proportional to the frequency.

D The damping force is always pointing towards the equilibrium point.

[ACJC 2015]

B

20 The diagram shows a transverse wave at a particular instant. The wave is travelling to the left. The frequency of the wave is 6.25 Hz.



At the instant shown, the displacement is zero at the point P.

What is the shortest time to elapse before the displacement is zero at point Q?

A 0.02 s **B** 0.06 s **C** 0.16 s **D** 0.20 s

[SRJC 2012]

Ans: B

$T = \frac{1}{f} = \frac{1}{6.25} = 0.16\,\text{s}$

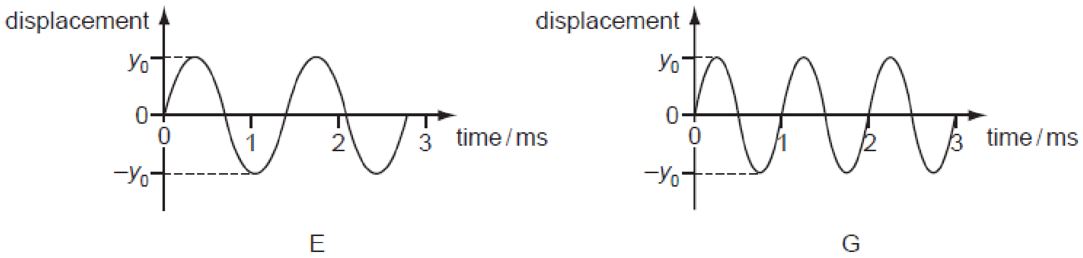
Each interval corresponds to 0.02 s.

To travel 3/8 of a wavelength, time needed

$= \frac{3}{8} \times 0.16$

$= 0.06\,\text{s}$

21 Two waves E and G are shown. The waves have the same speed.



Which of the following statements is correct?

A Wave E has a greater amplitude than wave G.

B Wave E has a greater intensity than wave G.

C Wave E has a smaller frequency than wave G.

D Wave E has a smaller wavelength than wave G.

[IJC 2013]

C
Period of E is ~ 1.3 ms, and frequency is 0.75 Hz.
Period of G is 1.0 ms, and frequency is 1.0 Hz.
Waves E and G have the same amplitude, yo, and hence they will have the same intensity.
Wavelength of wave E will be longer than wave G, as frequency of E is less than G.

22 Which of the following statements is true between a stationary and a progressive wave?

A A progressive wave would undergo plane polarisation while a stationary wave will not.

B The particles in a stationary wave are stationary while that of a progressive wave are vibrating.

C The particles in a progressive wave are oscillating at simple harmonic motion while those in a stationary wave are vibrating about their fixed positions.

D The particles in a stationary wave have varying amplitude while a progressive wave has particles with same amplitude.

[MI 2013]

D

23 Which of the following observations provides direct evidence that light is a transverse, rather than a longitudinal wave?

A We can hear but not see around corners.

B Lightning is seen before thunder is heard.

C Light reflected off the sea is cut-off when a sailor puts on a pair of sunglasses.

D Light can cause emission of electrons from the surface of a metal.

[JJC 2013]

C
Only transverse waves can be polarized, but not longitudinal waves. (Some sunglasses have polarized lens, i.e. the lens are actually a form of polarizing filters and block out certain orientations of light.)
Option A: Reason for this is due to the diffraction of sound waves but not light as the waves encounter the obstacle (the corner).
Option B: Reason being light travels faster than sound.
Option D: Reason being light may be considered as consisting of photons each with E= hf.

24 The frequency of a certain wave is 600 Hz and its speed is 330 ms^{-1}. What is the phase difference between the motions of two points on the wave 0.275 m apart?

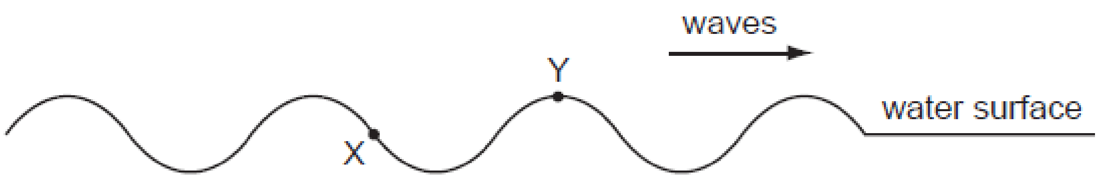
A 0 **B** $\frac{\pi}{4}$ rad **C** $\frac{\pi}{2}$ rad **D** π rad

[MJC 2012]

D: *$v = f\lambda$, λ = 0.550 m*

$$\Delta\phi = \frac{\Delta x}{\lambda} \times 2\pi = \frac{0.275}{0.550} \times 2\pi = \pi \text{ rad}$$

25 X and Y are two points on the surface of water in a ripple tank. A source of waves of constant frequency begins to generate waves which then travel past X and Y, causing them to oscillate.



What is the phase difference between X and Y?

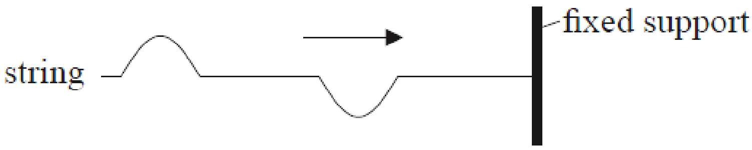
A 45° **B** 135° **C** 185° **D** 270°

[IJC 2013]

D

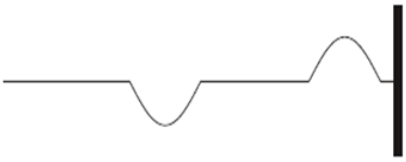
Point X is at the equilibrium position. Point Y is at the maximum positive displacement.
The phase angle between X and Y will be 180 + 90 = 270 deg.

26 A string is held horizontally with one end attached to a fixed support. Two pulses are created at the free end of the string. The pulses are moving towards the fixed support as shown in the diagram below.



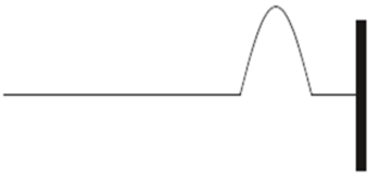
Which one of the following diagrams is a possible subsequent picture of the string?

A

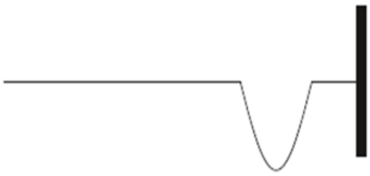


B

C



D

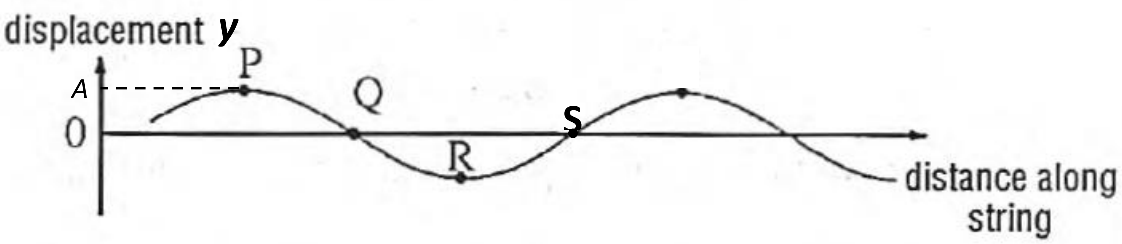


[MJC 2013]

C

The pulse reflects off the fixed support with a 180° phase change. Hence, the reflected pulse superimpose with the incoming pulse to give a resultant pulse that is of a higher amplitude than before.

27 The graph shows the shape at an instant t = 0 of part of a transverse wave travelling along a string from left to right.



Which of the following correctly gives the displacement-time description for particles P or S and the phase difference of the motion of S with respect to that of particle P?

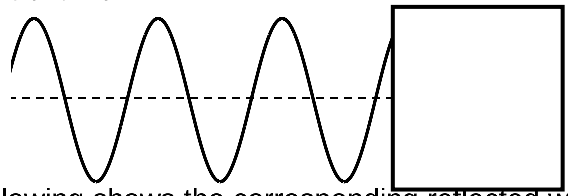
	Displacement-time relation of P or S	**Phase difference of S with respect to P**
A	$y_S = -A \sin \omega t$	$\frac{3}{4}\pi$
B	$y_P = A \sin \omega t$	$\frac{3}{4}\pi$
C	$y_P = A \cos \omega t$	$\frac{3}{2}\pi$
D	$y_S = -A \cos \omega t$	$\frac{1}{2}\pi$

[VJC 2013]

C

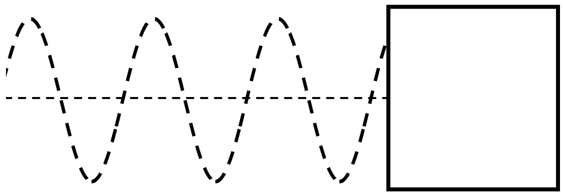
Particles P and S are separated by $\frac{3}{4}\lambda$. Hence the phase difference between them is $\frac{3}{2}\pi$ Particle P is at its amplitude position and is moving downwards as the wave propagates. Its displacement time equation is thus given by $y_P = A \cos \omega t$.

28 A progressive wave travelling to the right hits a solid surface and gets reflected after experiencing a phase change of π rad. The figure below shows the incident wave at a particular instant of time.

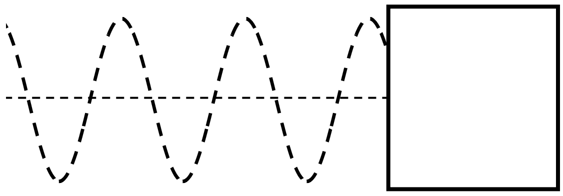


Which of the following shows the corresponding reflected wave?

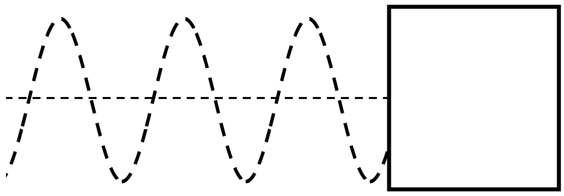
A



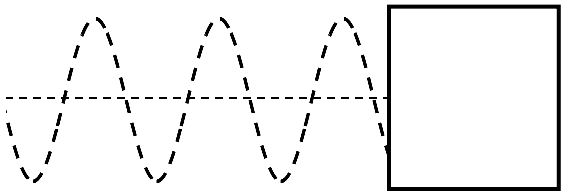
B



C

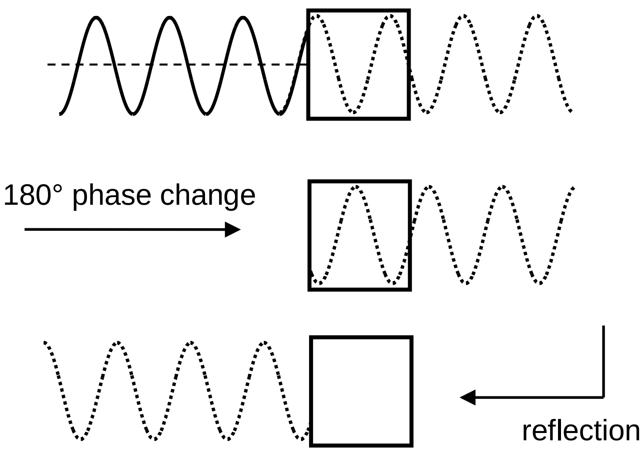


D



[JJC 2012]

C



29 A point source emits 60.0 W of sound. A small microphone of area 0.75 cm^2 detects the sound at 5.0 m from the source. What is the power detected by the microphone?

A 1.4×10^{-5} W **B** 1.4×10^{-4} W **C** 9.0×10^{-4} W **D** 1.4×10^{-1} W

[MJC 2012]

A

$$\text{Intensity} = \frac{\text{Power}}{\text{Area}}$$

Intensity at 5.0 m = $\frac{60}{4\pi(5.0)^2} = 0.191\ \text{Wm}^{-2}$

Hence, power received by earpiece= $0.191 \times \frac{0.75}{100^2} = 1.4 \times 10^{-5}$ W

30 A point source of sound emits energy equally in all directions at a constant rate and a person 9.0 m from the source listens. After a while, the intensity of the source is halved. If the person wishes the sound to seem as loud as before, how far should he be now from the source?

A 3.4 m **B** 4.5 m **C** 5.5 m **D** 6.4 m

[RVHS 2013]

D

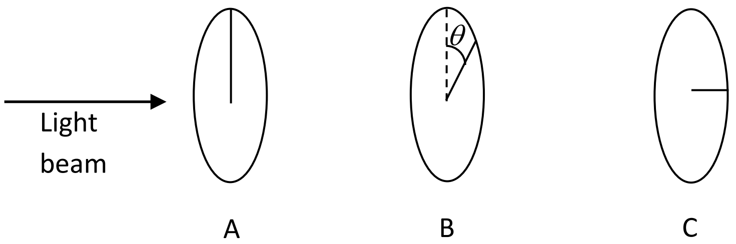
Intensity = Power/Area

$$\frac{P}{4\pi 9^2} = I_a$$

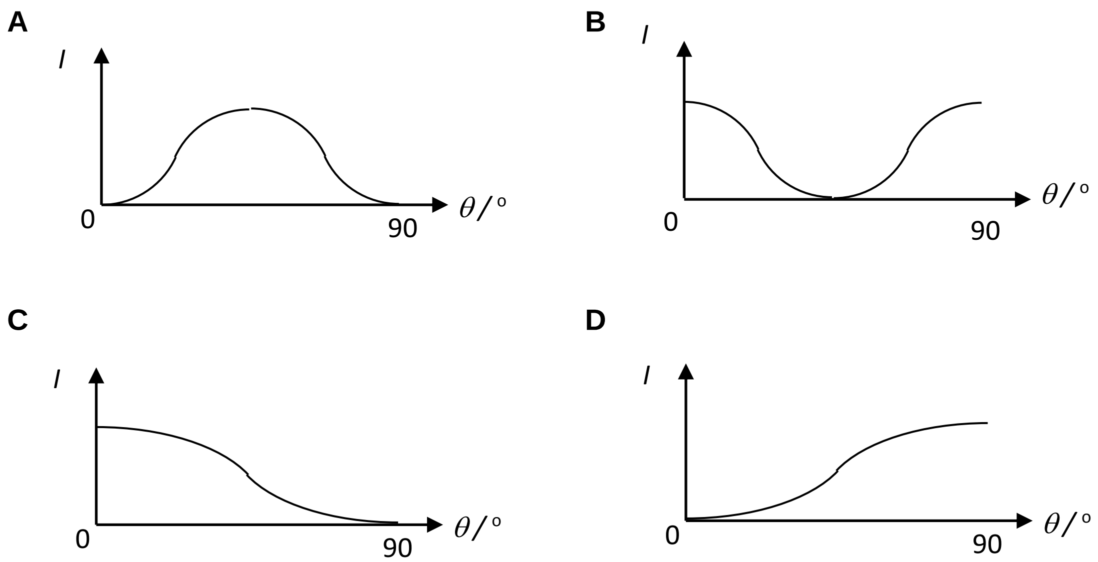
$$\frac{\left(\frac{1}{2}\right)P}{\left(\frac{1}{2}\right)4\pi r^2} = I_a$$

$$r = \sqrt{\frac{81}{2}} = 6.36\ m$$

31 Three polarisers are placed facing one another. The polarisation of polariser A is vertical, of B is at an angle of θ from the vertical, and of C is horizontal. A light beam is shone at A, as shown.



Which of the following graphs shows how the intensity *I* of the emergent light beyond C will vary with θ?



[VJC 2012]

ANS: A

When $\theta = 0^o$, the light will pass through A, be vertically polarised, and pass through B. But it will be blocked by C. Final intensity = 0.

When $\theta = 90^o$, the light will pass through A, be vertically polarised, and be blocked by B. Final intensity = 0.

When $0^o < \theta < 90^o$, the vertically polarised light after passing through A will have a component parallel to B. This component will pass through B. The resultant light will then be polarised parallel to B. Then when it reaches C, the horizontal component of the light will pass through C. Final intensity is non-zero.

32 The figure below shows a setup where a laser beam is directed towards two Polaroids. The Polaroids are adjusted such that zero intensity is detected by the light sensor. Without changing the orientation of either Polaroid A or Polaroid B, how can we adjust the setup such that the sensor may detect a non-zero intensity?

A Place another Polaroid between the laser and Polaroid A.

B Place another Polaroid between Polaroid A and Polaroid B.

C Place another Polaroid between Polaroid B and the light sensor.

D There is no possible method.

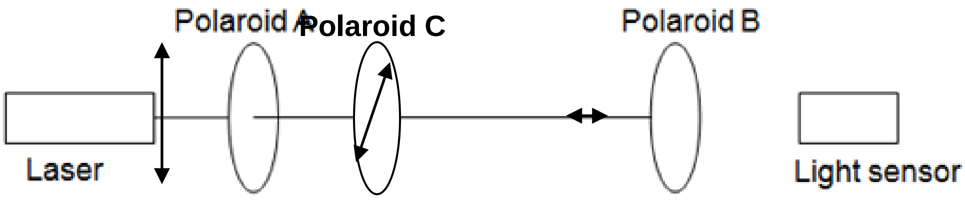
[JJC 2013]

B

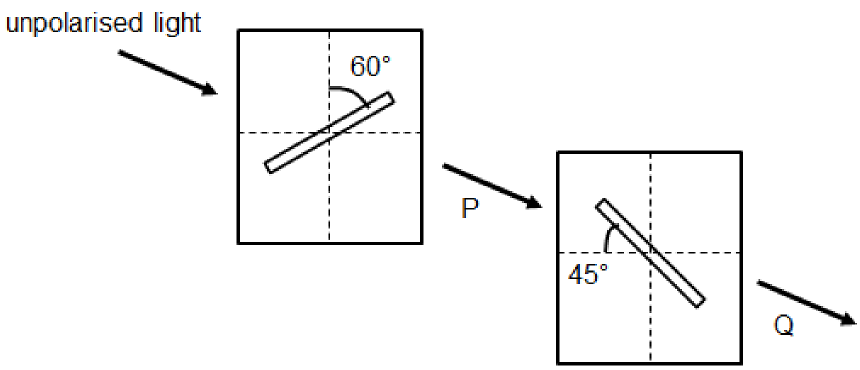
For zero intensity to occur at the light sensor, the polaroids' axes must be perpendicular to each other (for eg. with Polaroid A's polarizing axis perfectly vertical and Polaroid B's polarizing axis perfectly horizontal, as shown in diagram below).

By placing a third polaroid C with its polarizing axis at an angle, in between Polaroids A and B, a small amount of light that has passed through Polaroid A will also be able to pass through Polaroid C.

Likewise, a small component of the light that is able to pass through Polaroid C will also be able to pass through Polaroid B.



33 A beam of unpolarised light with amplitude A and intensity I is passed through two optical polarisers. The first polariser's transmission axis is oriented at 60° to the vertical, while the second polariser's transmission axis is oriented at 45° to the horizontal.



What is the intensity of the light at P and amplitude of the light at Q?

	Intensity of light at P	Amplitude of light at Q
A	$\frac{1}{4}I$	$\frac{1}{2}A\cos 15°$
B	$\frac{1}{4}I$	$\frac{1}{2}A\sin 15°$
C	$\frac{1}{2}I$	$\frac{1}{2}A\cos 15°$
D	$\frac{1}{2}I$	$\frac{1}{\sqrt{2}}A\sin 15°$

[RVHS 2013]

D

After passing 60°,

$P_{amplitude} = \frac{1}{\sqrt{2}}A \rightarrow P_{intensity} = ½ kA^2 = ½ I$

After passing 45°,

$Q_{amplitude} = \frac{1}{\sqrt{2}}A \sin 15$

34 The three lowest frequencies at which an ideal organ pipe resonates are 50 Hz, 150 Hz, and 250 Hz respectively. The speed of sound in air is 340 m s^{-1}.

Which of the following statements is correct?

A The pipe is open at both ends and has a length of 1.7 m.

B The pipe is open at both ends and has a length of 3.4 m.

C The pipe is open at one end, closed at the other, and has a length of 1.7 m.

D The pipe is open at one end, closed at the other, and has a length of 3.4 m.

[SRJC 2012]

C

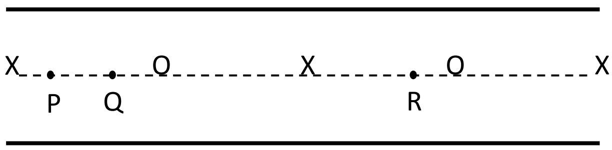
Since λ=v/f, the values of λ are 6.8 m, 2.27 m and 1.36 m.

With lowest f of 50 Hz,

if organ pipe is open at both ends, pipe length would be 3.4 m (0.5 λ) but λ would be 6.8 m, 3.4 m, 2.27 m => eliminate A and B

if organ pipe is open at one end and closed at the other, pipe length would be 1.7m (0.25 λ) and λ would be 6.8 m, 2.27 m and 1.36 m

35 Stationary sound waves are contained within a long glass tube. When a microphone is moved along a section of the tube, it detects points of high intensity marked X as well as points of zero intensity marked O.



Which set of values below shows the phase difference between point P and Q, and that of P and R?

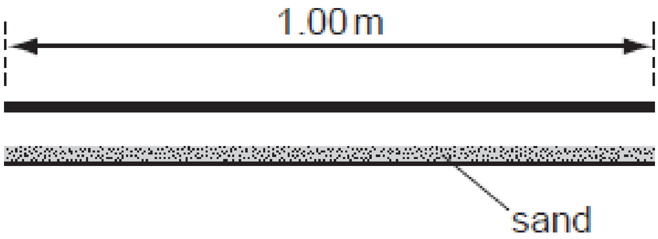
	P and Q	P and R
A	$\frac{\pi}{2}$ rad	π rad
B	$\frac{\pi}{4}$ rad	$\frac{\pi}{2}$ rad
C	0 rad	π rad
D	π rad	0 rad

[PJC 2012]

C

All points between two consecutive nodes of a stationary wave are in phase. Therefore, the phase difference between P and Q is 0 rad. However, all points within this half wavelength are anti-phase to all points in the adjacent half. Since R is in phase with points in the adjacent half, therefore the phase difference between P and R is π rad.

36 The diagram shows an air-filled pipe open at both ends. The length of the pipe is 1.00 m and the lower surface of the inside of the pipe is covered with a layer of fine sand.



When a source of sound of a single frequency is put near one end of the pipe, the air in the pipe is found to resonate and a pattern in the sand shows that a standing wave containing three heaps of sand formed within the pipe.

The speed of sound in air is 330 m s^{-1}. What is the frequency of the sound?

A 330 Hz **B** 495 Hz **C** 990 Hz **D** 1320 Hz

[IJC 2013]

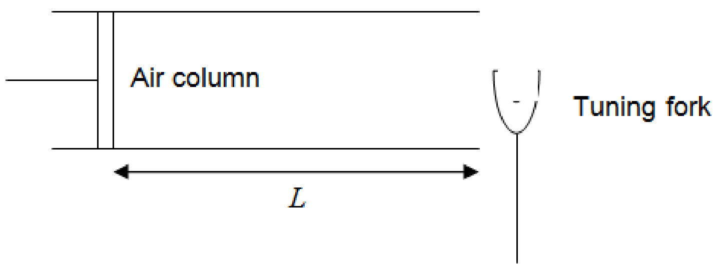
B

There will be antinodes at both ends of the pipe. This means that there will be a total of 1.5 wavelengths over a distance of 1.0 m.

Wavelength = 1.0 / 1.5 = 0.667 m

Frequency = speed / wavelength = 330 / 0.667 = 495 Hz

37 The length L of an air column is slowly increased from zero while a note of constant frequency is produced by a tuning fork placed in front of it.



When L reaches 20 cm the sound increases greatly in volume.
What is the wavelength of the sound wave produced by the tuning fork?

A 20 cm **B** 40 cm **C** 80 cm **D** 100 cm

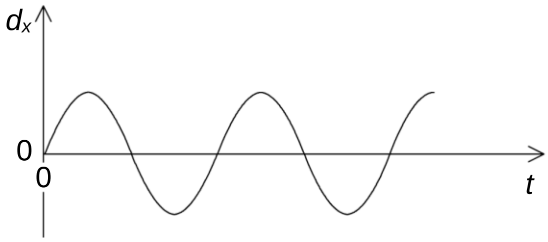
[IJC 2013]

C

Closed pipe 1st harmonic: λ = 4L

λ = 80 cm

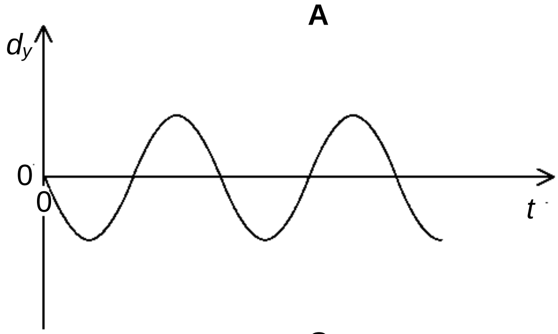
38 Two particles X and Y are situated a distance $\frac{1}{4}$ λ apart on a stationary wave of wavelength λ. There is an antinode between X and Y. The variation with time t of the displacement d_x of X is shown below.



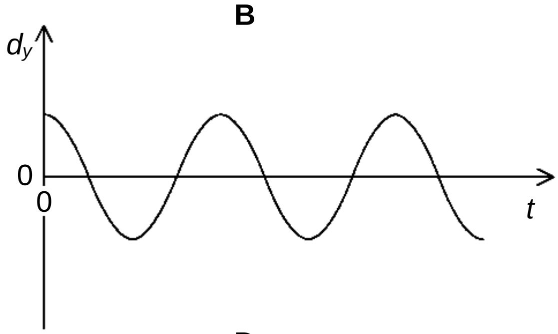
Which **one** of the following best shows the variation with time t of the displacement d_y of Y?

[AJC 2013]

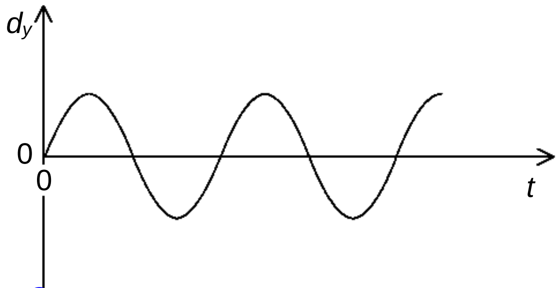
A



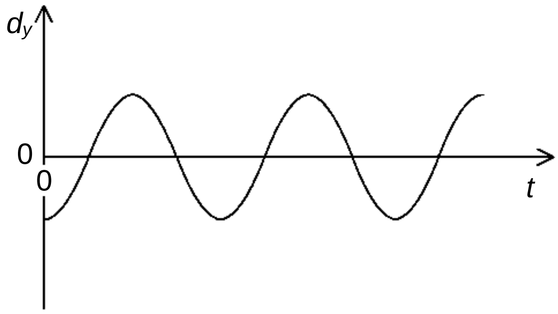
B



C



D



C

Since they are spaced a quarter wavelength from each other, with an antinode between them, they must be located within the same segment, in between two nodes. At any instant, all the particles in one segment are in phase.

39 Two pipes A and B are of the same length. Pipe A is closed at one end and pipe B is open at both ends. The fundamental frequency (first harmonic) of the closed pipe A is 220 Hz.

The best estimate for the fundamental frequency of the open pipe B is

A 880 Hz
B 440 Hz
C 110 Hz
D 55 Hz

[MJC 2013]

B

For pipe A, $L = 1/4\ \lambda_1$

$\lambda_1 = 4L$

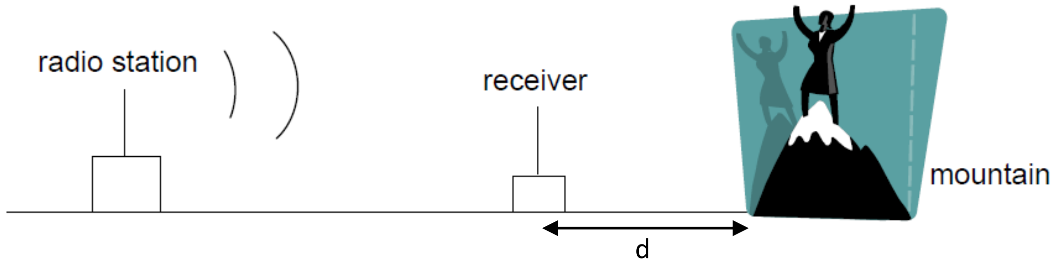
$f_1 = v/4L$

For pipe B, $L = ½\ \lambda_2$

$\lambda_2 = 2L$

$f_2 = v/2L = 2(v/4L) = 2f_1 = 2(220) = 440$ Hz

40 A radio station emits waves of wavelengths of 300 m. The waves arrive at a receiver from the radio station by two paths. One is a direct path, and the other a reflection from a mountain directly behind the receiver as shown below.



What is the minimum distance *d* from the mountain to the receiver such that destructive interference occurs at the receiver?

A 75 m **B** 200 m **C** 300 m **D** 600 m

C

Since one of the sources is reflected by the mountain => sources are in antiphase.

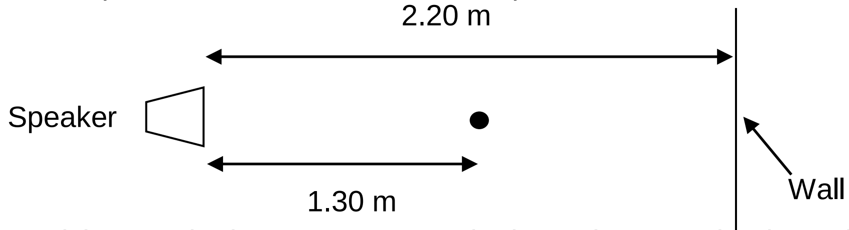
For sources in phase to meet destructively, phase diff = π, 3π, 5π …

Since the path difference is made up of twice the dist between receiver and mountain,

Total phase diff = $((2d/300) \times 2\pi) + \pi$

[SRJC 2012]

41 A student places a speaker 2.20 m from a wall. It emits a sound wave of wavelength 0.50 m towards the wall. The wave gets reflected and interferes with the incoming wave from the speaker. A microphone connected to a CRO is placed 1.30 m from the speaker, as shown below.



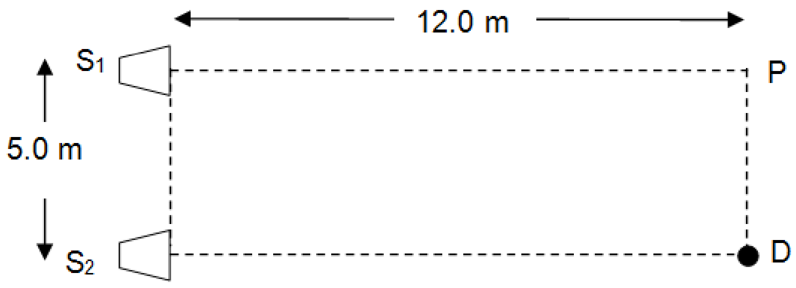
The student wishes to obtain a constant amplitude on the CRO, but is unable to do so. What is the reason for this?

A The distance between the speaker and the wall is of the wrong value.
B The wall absorbs some of the sound energy.
C The microphone is not placed at the node.
D The microphone is not placed at the antinode.

[VJC 2012]

A For a stationary wave to form, a whole number of segments (=$\lambda/2$) must be able to fit in the space between the speaker and the wall. But 2.20 m doesn't satisfy this condition.

42 Two sound sources S_1 and S_2, which are separated by 5.0 m, are connected to a signal generator such that they produce coherent waves which are completely out of phase. A detector D is placed 12.0 m directly in front of source S_2 as shown in the diagram below. The signal generator is set to a frequency of 680 Hz.

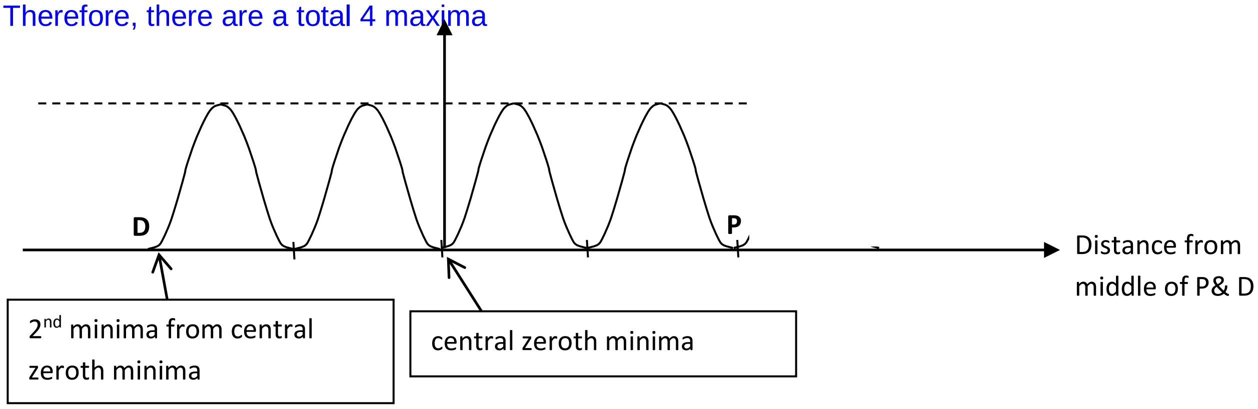


Given that the speed of sound is 340 m s^{-1}, how many sound maximas will the detector detect as it moves from point D to point P, which is directly in front of source S_1?

A 2 **B** 3 **C** 4 **D** 5

[MJC 2012]

C
For v=f λ ; λ = 0.5 m
Distance S_1D = 13 m
Distance S_2D = 12 m
Therefore, path difference between S_1D & S_2D = 1.0 m = 2 λ
At point D, it is a minima which corresponds to the 2nd minima from the zeroth minina order.
Therefore, there are a total 4 maxima



43 Two light sources produce visible interference fringes only in certain circumstances. Which condition enables visible interference fringes to be formed?

A using a white light source
B using incoherent sources
C using one light source which is polarised at right angles to light from the other source
D using sources from which the light does not overlap

[AJC 2013]

A: To observe visible interference fringes, sources must be coherent and either unpolarised or polarised in the same plane and the two sources must be close so that the two waves overlap.

44 Plane waves of wavelength λ in a ripple tank travel towards a straight barrier parallel to the wave fronts. There are 2 gaps of identical width, spaced d apart. Which of the following λ and d will produce the narrowest-spaced interference patterns at a screen distance D away?

	λ / cm	***d* / cm**
A	1.3	2.3
B	1.3	5.2
C	2.6	5.2
D	2.6	2.6

[RVHS 2013]

B

x = (1.3)(D)/(5.2) = 0.25D

45 Interference maxima produced by a double source are observed at a distance of 1.0 m from the sources. In which one of the following cases are the maxima closest together?

A sound waves of wavelength 20 mm from sources 50 mm apart
B surface water waves of wavelength 10 mm from sources 200 mm apart
C red light from sources 4.0 mm apart
D blue light from sources 2.0 mm apart

[MJC 2013]

C

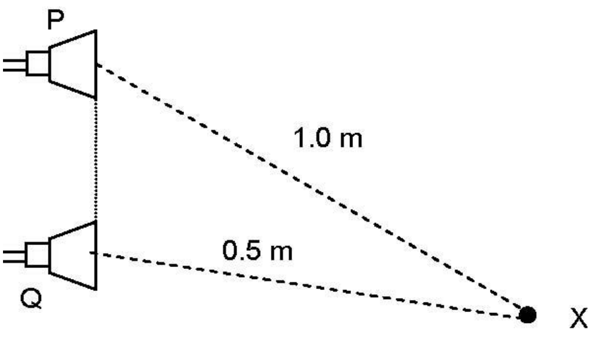
Maxima closest = Fringe separation, x, is the smallest. Using x= λD/a

For same D, x ∝ λ/a. Smallest λ/a ratio is option C

46 Microwaves of wavelength 20.0 cm are produced by two microwave transmitters P and Q operating in phase. Point X is 1.0 m from transmitter P and 0.5 m from transmitter Q as shown in the figure below.

Microwaves from transmitter P arrive at point X with intensity *I* and amplitude of oscillation *A* while the microwave from transmitter Q arrives at point X with intensity 4*I*.

Determine the resultant intensity at X in terms of *I*.



1.

A zero **B** *I* **C** 3 *I* **D** 9 *I*

[JJC 2012]

B

50 = 2.5 x 20

This means that path difference = 2.5 x wavelength

So destructive interference at ***X***

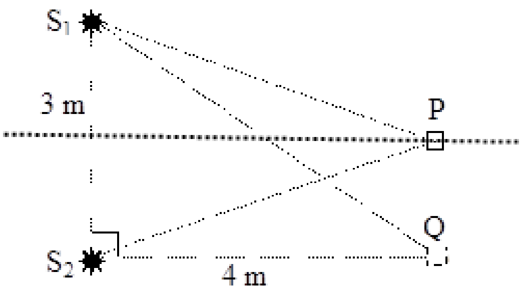
$$\frac{I}{4I}=\left(\frac{A_P}{A_Q}\right)^2$$

$$A_Q = 2A_P = 2A$$

Resultant amplitude $= A_Q - A_P = 2A - A = A$

Hence resultant intensity $= I$

47 Two sources of waves, S1 and S2, are situated as shown in figure below. Individually, each source emits waves of intensity I.



A detector at P equidistant from S1 and S2, registers a steady minimum wave intensity. The same detector registers the next steady minimum intensity when it moves to point Q.

Which of the following statements about the two sources of waves is not valid?

A The two sources of waves are coherent.
B The two sources of waves have wavelength of 2 m.
C The two sources of waves have a phase difference of π radians.
D The two sources of waves have the same amplitude.

[MI 2013]

B

Δx = 5 – 4 = 1 m

Since min intensity at centre, 2 sources are out of phase

Δx of 1 m will cause the waves to get back into phase if λ is 2 m.

48 The interference patterns from a diffraction grating and a double slit are compared. Using the diffraction grating, yellow light of the first order is seen at 30° to the normal to the grating. The same light produces interference fringes on a screen 1.0 m from the double slit. The slit separation is 500 times greater than the line spacing of the grating.

What is the fringe separation on the screen?

A 2.5×10^{-7} m **B** 1.0×10^{-5} m **C** 1.0×10^{-3} m **D** 1.0×10^{-1} m

[AJC 2012]

C

For diffraction grating, $d_g \sin\theta = n\lambda \Rightarrow d_g = \dfrac{(1)\lambda}{\sin 30°}$

For double slit, $x = \dfrac{\lambda D}{d_d} = \dfrac{\lambda D}{500 d_g} = \dfrac{\lambda D}{500\left(\dfrac{(1)\lambda}{\sin 30°}\right)} = \dfrac{\lambda (1.0)}{500\left(\dfrac{(1)\lambda}{\sin 30°}\right)} = 1.0 \times 10^{-3}$ m

49 A diffraction grating ruled with 5000 lines per cm is illuminated with white light.
If the wavelength for yellow light and violet light are 600 nm and 400 nm respectively, which one of the following statements is NOT correct?

A The central image is white.
B The second-order image of the yellow light coincides with the third-order image of violet light.
C There is no fourth-order image for yellow light.
D The red end of the first-order spectrum is closer to the central image than the violet end of the first-order spectrum.

[JJC 2012]

D: A is correct.

B is correct.

$$n_y \lambda_y = n_v \lambda_v$$

$$\frac{\lambda_y}{\lambda_v} = \frac{n_v}{n_y}$$

$$\frac{600}{400} = \frac{n_v}{n_y} = \frac{3}{2}$$

C is correct.

$$n \le \frac{d}{\lambda}$$

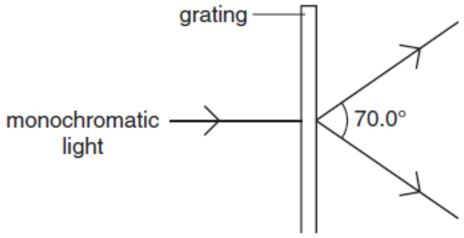
$$\le \frac{1 \times 10^{-2}}{5000} \times \frac{1}{600 \times 10^{-9}}$$

$$\le 3.33$$

D is incorrect

Red light will diffract more than violet light because red light has longer wavelength than violet light.

50 A diffraction grating is used to measure the wavelength of monochromatic light, as shown below.



The spacing of the slits in the grating is 1.00 x 10–6 m. The angle between the first order diffraction maximas is 70.0°.

What is the wavelength of the light?

A 287 nm **B** 470 nm **C** 574 nm **D** 940 nm

[IJC 2013]

C

Using, d sin θ = nλ

λ = (d sinθ) / n

For the question, n = 1, θ = 70 / 2 = 35º, d = 10^{-6} m,

λ = (10^{-6}) (sin 35) / (1)

= 574 nm

51 Two monochromatic radiations X and Y are incident normally on a diffraction grating. The second order intensity maximum for X coincides with the third order intensity maximum for Y.

What is the ratio $\frac{\text{wavelength of X}}{\text{wavelength of Y}}$?

A 75 m **B** 200 m **C** 300 m **D** 600 m

[PJC 2012]

C: $d\sin\theta_x = 2\lambda_x$

$d\sin\theta_y = 3\lambda_y$

Since the same diffraction grating is used, *d* is the same. The maximum intensity of the radiations coincides, which means that both $\sin\theta_x$ and $\sin\theta_y$ are the same.

$2\lambda_x = 3\lambda_y$

$$\frac{\lambda_x}{\lambda_y} = \frac{3}{2}$$

52 A beam of monochromatic light of wavelength 550 nm is incident normally on a diffraction grating that has 300 lines per mm.What is the total number of images produced by light transmitted through this grating?

A 6 **B** 7 **C** 12 **D** 13

[MI 2013]

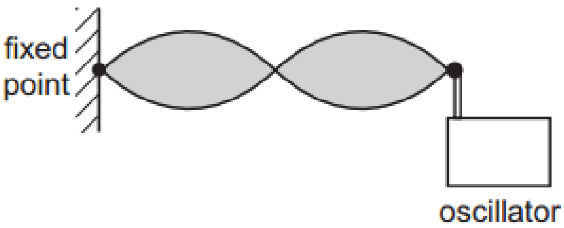
D

$$d\sin\theta = n\lambda$$

$$\sin\theta = \frac{n\left(550\times 10^{-9}\right)}{\frac{1}{300000}} = 0.165n \quad \text{n <7}$$

Total images = 6 + 1 + 6 = 13

53 The speed of a transverse wave on a stretched string can be changed by adjusting the tension of the string. A stationary wave pattern is set up on a stretched string using an oscillator set at a frequency of 650 Hz.



How must the wave be changed to maintain the same stationary wave pattern if the applied frequency is increased to 750 Hz?

A Decrease the speed of the wave on the string.

B Decrease the wavelength of the wave on the string.

C Increase the speed of the wave on the string.

D Increase the wavelength of the wave on the string.

[AJC 2015]

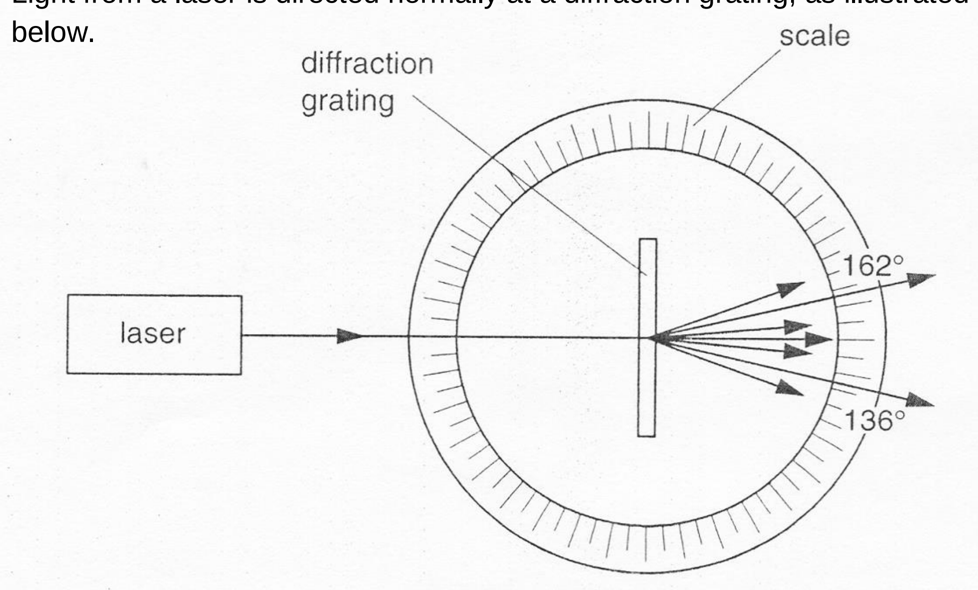
C

$$v = f\lambda \rightarrow \lambda = \frac{v}{f}$$

To produce the same wave pattern, the wavelength must remain constant.

To maintain the same wavelength at a higher frequency, the speed must be increased.

54 Light from a laser is directed normally at a diffraction grating, as illustrated in figure below.



The diffraction grating is situated at the centre of a circular scale, marked in degrees. The readings on the scale for the second order diffracted beams are 136° and 162°.

The wavelength of the laser light is 630 nm. The spacing of the slits of the diffraction grating is

A 5.60×10^{-6} m **B** 2.87×10^{-6} m **C** 2.80×10^{-6} m **D** 1.40×10^{-6} m

[NJC 2015]

A

$n\lambda = dsin\theta$

$\theta = \frac{162° - 136°}{2} = 13°$

$2 \times 630 \times 10^{-9} = dsin13° \rightarrow 5.60 \times 10^{-6} m$

Short Structured Questions

1 **(a)** State what is meant by

(i) a free oscillation. [1]

(ii) a damped oscillation. [1]

(iii) a free oscillation. [1]

(b) A car component of mass 0.0460 kg rattles at a resonant frequency of 35.5 Hz. Fig. 1.1 shows how the amplitude of the oscillation varies with frequency.

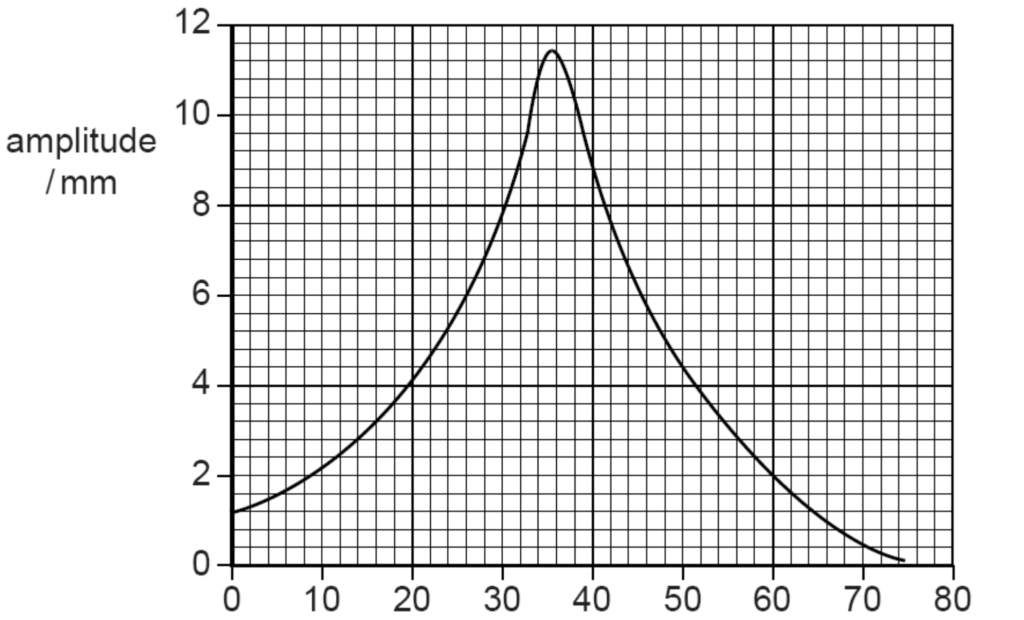


Fig. 1.1

(i) Calculate the energy stored in the component when oscillating at the resonant frequency. [2]

energy = ... J

(ii) Explain why there is a peak at frequency 35.5 Hz. [1]

(iii) On Fig. 1.1, draw a line to show the effect of supporting the component on a rubber mounting. [2]

[AJC 2013 P2]

1 **(a)** **(i)** Free Oscillation is an oscillation which occurs at the <u>natural frequency</u> of a body when displaced from the equilibrium position and allowed to oscillate freely <u>without the application of any external periodic force</u>.
OR
an oscillation in which <u>frictional / resistive forces are negligible</u>.

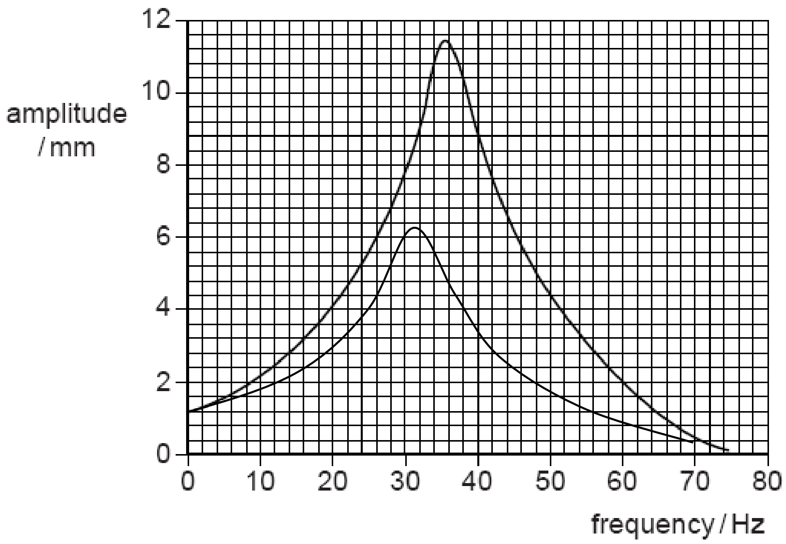
(ii) an oscillation where the <u>amplitude is decreasing</u> OR
an oscillation where <u>frictional / resistive forces exist</u> OR
where the <u>energy of the oscillation is decreasing</u>

(iii) Forced Oscillation is produced when a system is acted upon by an external periodic driving force.
Or
An oscillation where the amplitude is maintained by energy being supplied by an external source.

(b) **(i)** At the resonant frequency $\omega = 2\pi f = 2\pi \times 35.5 = 223$ rad s^{-1}
$E = \frac{1}{2} mA^2\omega^2$, where A = 0.0114
$= \frac{1}{2} \times 0.046 \times 0.0114^2 \times 223^2 = 0.149$ J

(ii) 35.5 Hz is the natural frequency of the component, and this is at the driver frequency so resonance occurs with the largest amplitude

(iii)



Same starting point and lower graph peak
Maximum amplitude at lower frequency within original shape

2 Fig. 2.1 shows a mass-spring system consisting of an air track vehicle V of mass 0.60 kg. A peg attached to V is connected to two identical springs that are both fixed at the other end. Each spring has a spring constant of 7.5 N m^{-1}. When V is displaced along the air track and released it oscillates about its rest position. The vehicle V floats on a cushion of air so that there is negligible friction between V and the air track.

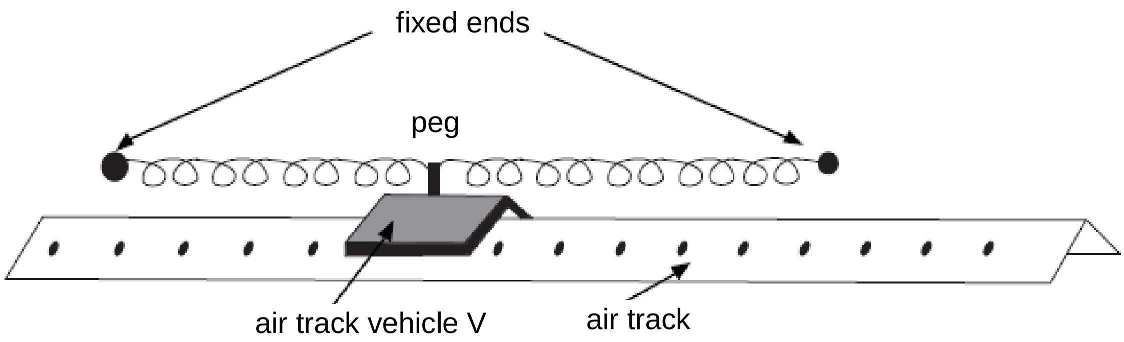


Fig. 2.1

Fig. 2.2 shows how the kinetic energy E_k of V varies with its displacement *s* from the rest position when the initial displacement is 0.16 m.

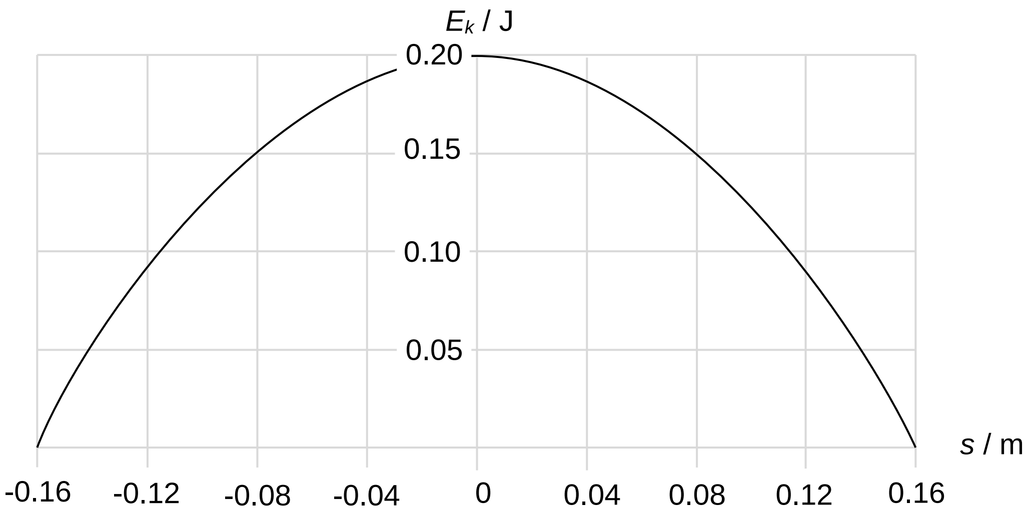


Fig. 2.2

(a) Draw on Fig. 2.2 a graph showing how the potential energy of the mass-spring system varies with *s*. Label the graph *U*. [2]

(b) The system loses 25% of its total energy. Use Fig. 2.2 to determine the new amplitude of oscillation. Explain your working. [2]

new amplitude = ... m

(c) Draw on Fig. 2.2 a graph to show how the kinetic energy of V would vary with *s* when the initial displacement is 0.080 m. Label the graph *K*. [2]

[TJC 2013 P2]

2 (a) Correct general shape (0.2 J at ± 0.16 m and 0 at centre) B1
Crossing at 0.1 J B1

(b) New max PE = 0.15 J B1
From PE graph drawn in (a), with 0.15 J, amplitude is 0.14 m. A1
Or move the x-axis up by 0.05 J, from the KE graph, amplitude is 0.14m.

(c) Graph showing zero at ±0.08 m rising to a peak ≤ 0.1 J at 0. B1
Maximum shown as 0.05 J. B1
<u>Comments:</u> Majority of the students were able to gain very good credits, however they should pay attention to details when plotting the graphs, e.g. crossing should be at 0.1 J.

3 **(a)** When a force is applied to a vertical spring-mass system, Fig. 3.1 shows the subsequent displacement-time graph. The system is performing simple harmonic motion.

The period of oscillation of a loaded spring is $T = 2\pi\sqrt{\dfrac{m}{k}}$ where *m* is the mass on the spring and *k* is the spring constant.

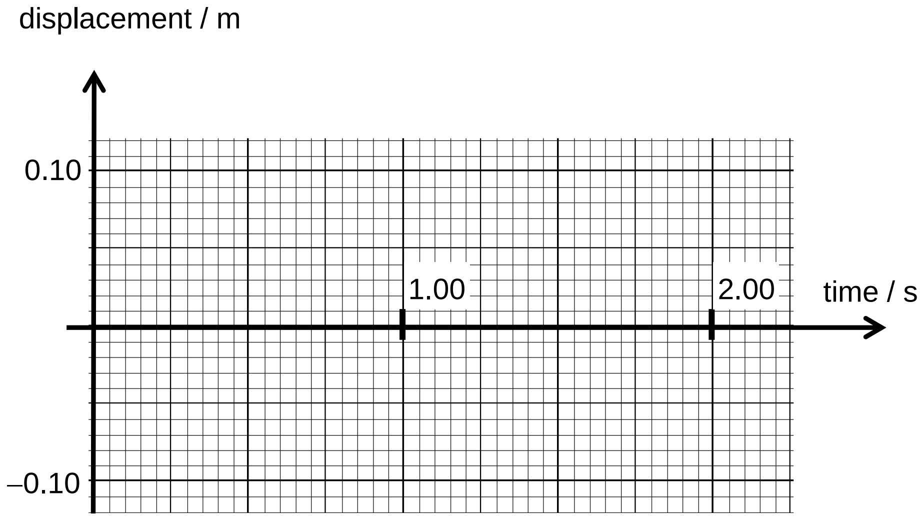


Fig. 3.1

Fig. 3.2 shows how the total potential energy of the spring-mass system varies with displacement.

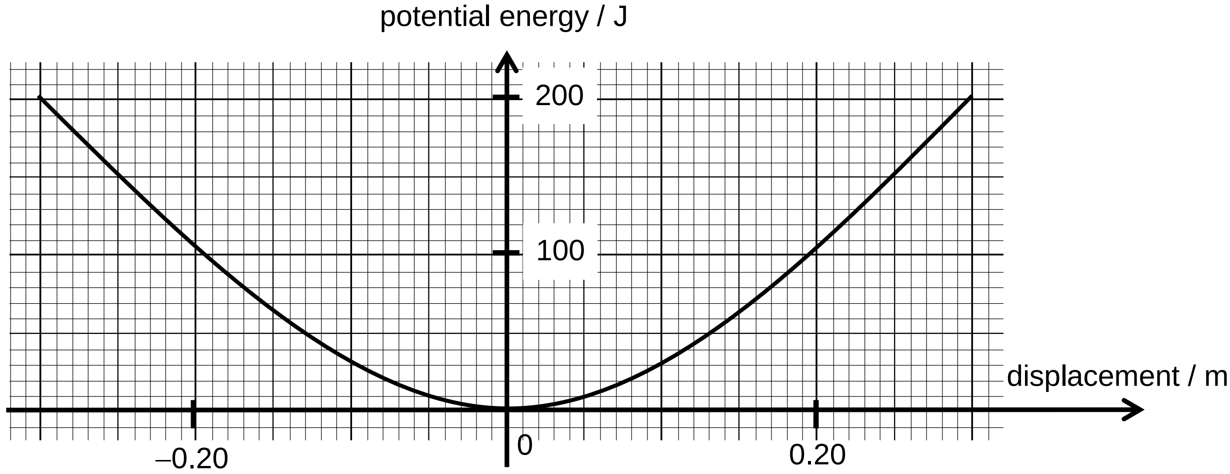


Fig. 3.2

(i) Calculate the spring constant *k*, of the system. [2]

k = ... N m^{-1}

(ii) Show that when an identical spring is added in parallel and displaced with the same force, shown in Fig. 3.3, the effective spring constant is 2k. [2]

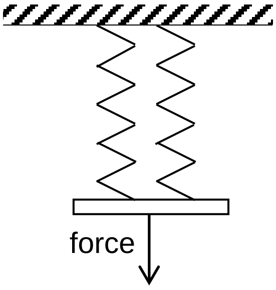


Fig. 3.3

(b) Define *resonance* and name one circumstance in which resonance is useful. [2]

(c) The spring in **(a)** is installed on each of the wheels of a motor car, which is used to test a speed bump system by driving at different speeds over a series of equally spaced bumps.
When the motor car is driven at a particular speed over the speed bumps, the amplitude of vibration of the car is maximum.
Given that the separation of the bumps is 20 m and the combined mass of the car and driver is 1000 kg, calculate the speed of the car. [2]

speed = ... m s^{-1}

(d) Suggest 2 reasons why resonance is seldom experienced under normal driving conditions. [2]

[RVHS 2013 P2]

3 **(a)** **(i)** Total Energy, $E_T = ½\, k\, x_o^{\,2}$ M1

$\Rightarrow 30 = ½\, k\, (0.10)^2$

$\Rightarrow k = 6000 \text{ N m}^{-1}$ A1

(ii) $F = kx$

For a parallel springs system, Force acting on each spring is $F/2$. M1

Extension = $x/2$

For the whole System, Force = F and Extension = $x/2$. M1

$k_{//} = 2k$

(b) Resonance occurs when the driving frequency to a system match the natural frequency of that system. B1

Occurs in most musical instruments. B1

(c) When a particular speed of the motorcycle reached gives a larger amplitude of vibration → the natural frequency of the car's suspension system is reached

To achieve resonance, $f = f_0 = \dfrac{1}{2\pi}\sqrt{\dfrac{k}{m_{system}}}$

$k = 4 \times 6000 = 24000$

$f_0 = \dfrac{1}{2\pi}\sqrt{\dfrac{24000}{1000}} = 0.78\,\text{Hz}$ M1

A1

v = Distance / time = 1/0.78 × 20 = 15.6 m s^{-1}

(d) Damping, B2
rarely are there evenly spaced bumps,
usually there is variation in mass and speed. Either 2

4 A block of mass M = 200 g attached to a horizontal spring of spring constant k = 5.00 N m^{-1} is shown in Fig. 4.1. The spring-block system is set into simple harmonic motion with amplitude A = 5.00 cm. The period of oscillation, T, of a spring-mass system is given by $T = 2\pi\sqrt{\dfrac{M}{k}}$.

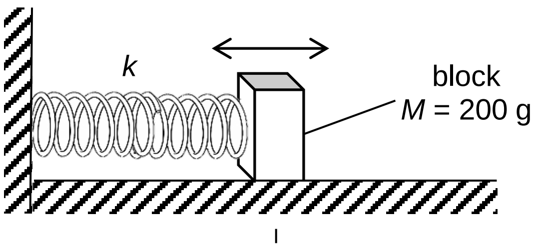


Fig. 4.1

(a) Determine the period of oscillations. [1]

period = ... s

(b) As the block passes through the equilibrium position, a small mass m = 20.0 g is dropped vertically from a small height and sticks to it, as shown in Fig. 4.2.

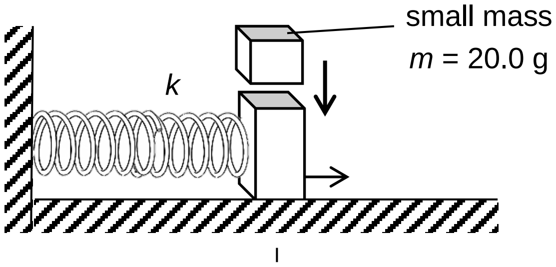


Fig. 4.2

(i) Show that the speed of the combined mass immediately after the small mass is stuck to the block at the equilibrium position is 0.227 m s^{-1}. [2]

(ii) Hence determine the new amplitude of oscillations of the combined mass. [2]

new amplitude = ... cm

(c) If instead, the small mass *m* is dropped vertically onto the block when it is at one end of its path as illustrated in Fig. 4.3.,

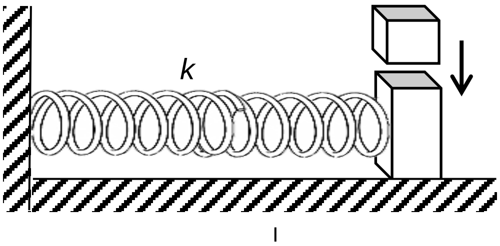


Fig. 4.3

(i) state and explain the change, if any, in the amplitude of these new oscillations as compared to amplitude *A*. [2]

(ii) state and explain the change, if any, in the period of these new oscillations as compared to that calculated in part **(a)**. [1]

[DHS 2013 P2]

4 (a) period = $2\pi\sqrt{(M/k)}$ = 1.26 s A1

(b) (i) At equilibrium point before collision

Speed, $u = wA = (\sqrt{5/0.2})(0.05)$ = 0.250 m s^{-1} C1

Total momentum before collision = total momentum after collision

$M\,u = (m+M)\,v$

$v = (0.2)(0.25)/(0.2+0.02)$ M1

v = 0.227 m s^{-1} A0

Comments: A significant number of students did not realize that this is an inelastic collision problem and the total KE is not conserved. Also in such a derivation problem, it is expected that adequate explanation is given and all the steps are shown.

(ii) Based on conservation of energy,

Loss in KE = gain in EPE

$\frac{1}{2}(M + m)\,v^2 = \frac{1}{2}k(A_1)^2$

$\frac{1}{2}(0.200 + 0.020)(0.227)^2 = \frac{1}{2}(5)(A_1)^2$ C1

A_1 = 4.76 cm A1

(c) (i) Total energy of the spring – mass system remains the same at $E = \frac{1}{2} kA^2$ B1
The amplitude of the new oscillation remains the same. A1

Comments: Many students were not aware that there is no loss of energy (i.e. total KE + EPE) in this part of question.

(ii) Given $T = 2\pi\sqrt{M/k}$, mass increases and hence the period is longer. A1

5 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. [2]

phase difference = ... rad

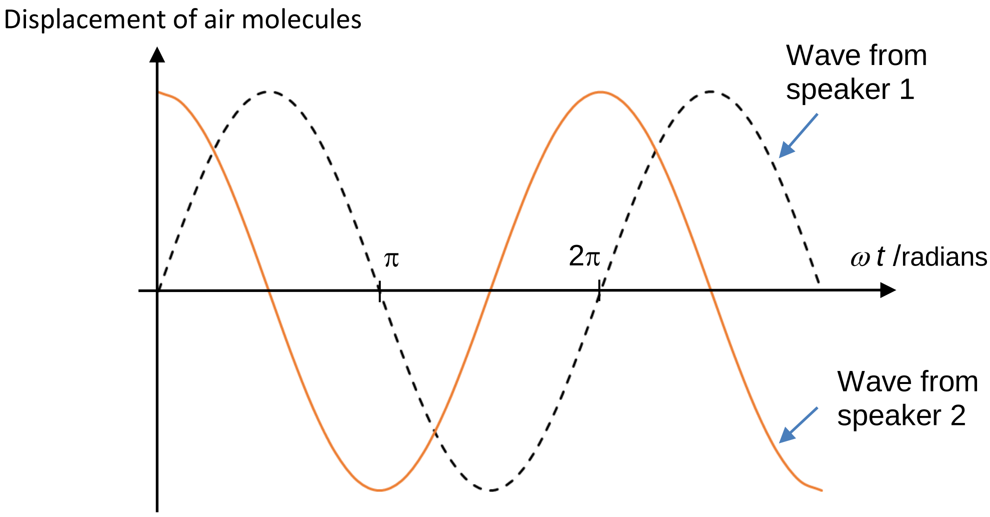
(b) Determine the resultant sound intensity that the listener hears. Express your answer in terms of I_o. [2]

resultant intensity = ...

(c) Determine the ratio of the power of loudspeaker A to the power of loudspeaker B, assuming the loudspeakers are point sources of sound. [2]

ratio = ...

(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.



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. [3]

resultant intensity = ...
[HCI 2013 P2]

5 **(a)** Path difference $\delta = 11.0 - 8.0 = 3.0$ m [1]

Phase difference = $\dfrac{\delta}{\lambda}.2\pi = \dfrac{3.0}{340/680}.2\pi = 12\pi$ radians [1]

Accept zero radians.

(b) $A_{net} = A_o + A_o = 2A_o$ (waves arrived in phase ⇒ constructive interference) [1]

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

Thus $I_{net} = \dfrac{A_{net}^2}{A_o^2} I_o = \left(\dfrac{2A_o}{A_o}\right)^2 I_o = 4I_o$ [1]

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

$\dfrac{P_A}{4\pi r_A^2} = \dfrac{P_B}{4\pi r_B^2}$ [1]

$\dfrac{P_A}{P_B} = \left(\dfrac{r_A}{r_B}\right)^2 = \left(\dfrac{8.0}{11.0}\right)^2 = 0.53$ [1]

(d) From graph, resultant wave has maximum displacement when $\omega t = \pi/4$ or 45° [1]

$A_{net} = A_o \sin(\pi/4) + A_o \cos(\pi/4) = \sqrt{2}\, A_o$ [1]

$I_{net} = 2\, I_o$ [1]

6 **(a)** A transverse progressive wave travels from left to right. The variation with distance x of the displacement y of the transverse wave is shown in Fig. 6.1.

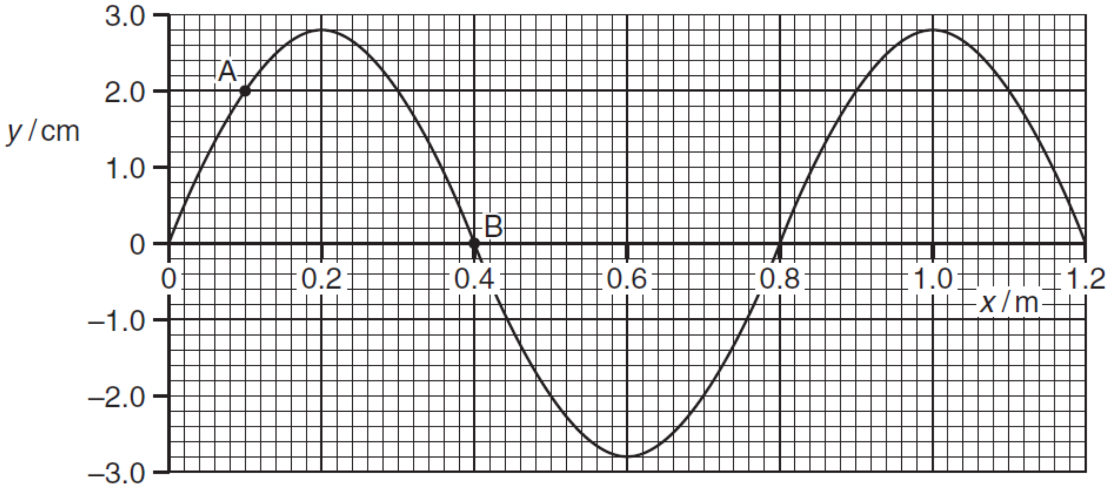


Fig. 6.1

The frequency of the wave is 15 Hz.

For this wave, use Fig. 6.1 to determine

(i) the phase difference between the points labelled A and B, [1]

phase difference = ... rad

(ii) the speed of the wave. [2]

speed = ... m s^{-1}

(b) The period of vibration of the wave is T. The wave moves forward from the position shown in Fig 6.1 for a time $0.25T$. On Fig. 6.1, sketch the new position of the wave. [2]

(c) A stretched string is used to form a stationary wave. Part of this wave, at a particular instant, is shown in Fig. 6.2.

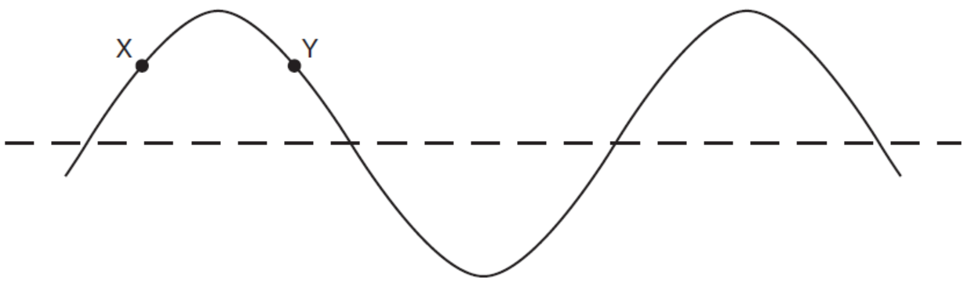


Fig. 6.2

The points on the string are at their maximum displacement.

(i) State the phase difference between the particles labelled X and Y. [1]

phase difference = ... rad

(ii) The period of vibration of this wave is τ. On Fig. 6.2, sketch the stationary wave 0.25 τ after the instant shown in Fig. 6.2. [1]

[RJC 2013 P2]

6 **(a)** **(i)**

$$\Delta\phi = \frac{\Delta x_{AB}}{\lambda}(2\pi) = \frac{(0.30\text{ m})}{(0.80\text{ m})}(2\pi) = \frac{3}{4}\pi \text{ rad or } 0.75\pi \text{ rad or } 2.36 \text{ rad}$$

(ii)

$$v = f\lambda = (15\text{ Hz})(0.80\text{ m}) = 12\text{ m s}^{-1}$$

(b)

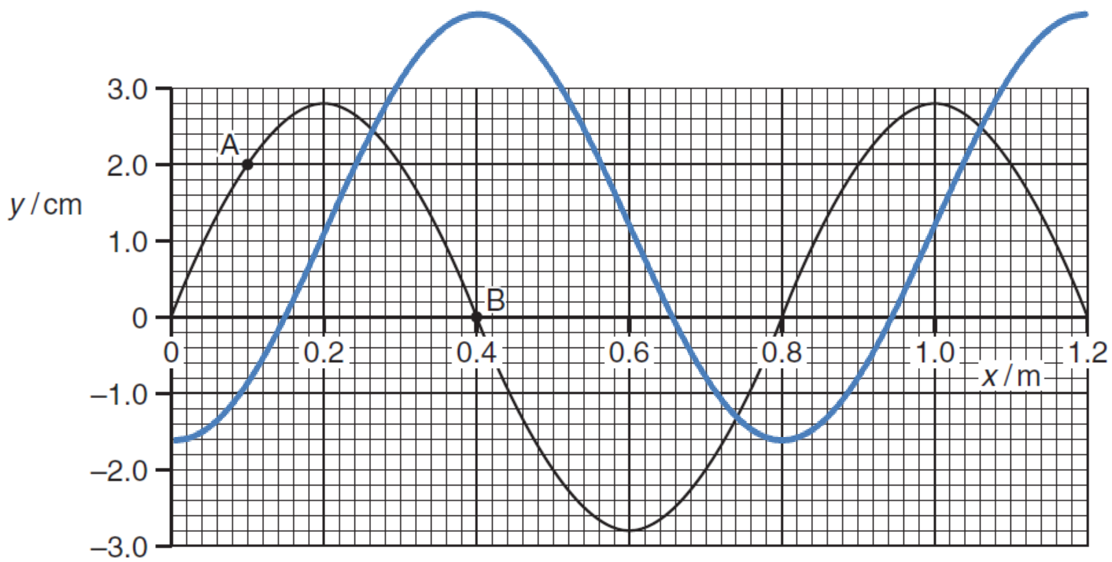


Fig. 2.1

Correct sketch with peak moved to the right; wave profile moved by the correct distance of 0.20 m.

(c) **(i)** Zero rad. All points between adjacent nodes oscillate in phase with each other; they are π rad out of phase with all points in the next half-wavelength section.

(ii)

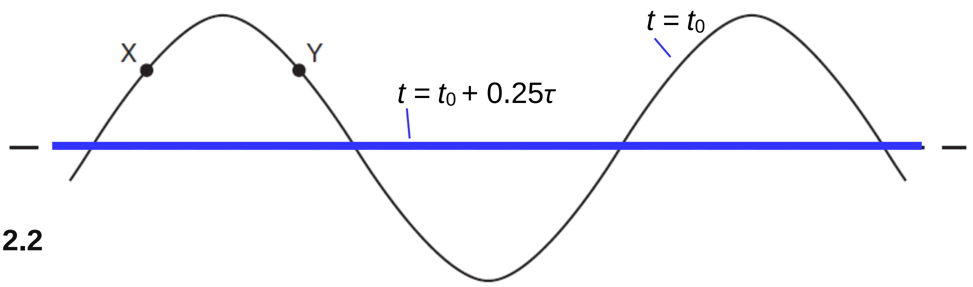


Fig. 2.2

At the time 0.25τ after the instant shown in Fig. 2.2, the individual traveling waves are π rad out of phase, and each element of the medium is passing through the equilibrium position in its simple harmonic motion. The result is zero displacement for elements at all values of x; that is, the wave pattern is a straight line.

7 After World War II, radar antennas mounted at the edge of sea-cliffs were re-purposed to observe radio signals originating from outer space.

One such set up is shown in Fig. 7.1. The height of the antenna above the sea is H.
In this case, radio waves of frequency 20 MHz from the Sun arrive at the antenna at a angle of θ from the vertical. As the Earth rotates from west to east, this angle θ changes with time.

As the Sun is so far away, the incoming rays are practically parallel to one another.
Two such rays of radio waves are shown. One ray travels directly to the antenna, while the other ray is reflected off the sea surface before it reaches the antenna after undergoing a phase change of 180° during the reflection.

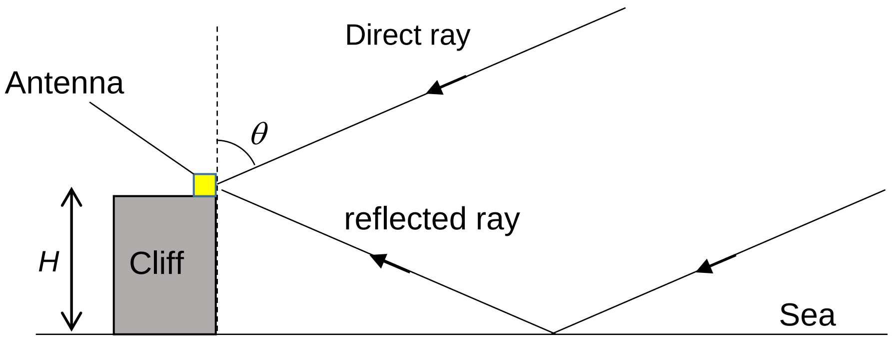


Fig. 7.1

(a) Calculate the wavelength of the radio waves.

Wavelength = ……………………. m [1]

By treating the sea surface as a perfectly flat mirror, the difference Δx in the distances travelled by the direct and reflected rays before they reach the antenna is found to be

$$\Delta x = 2H\cos\theta$$

As the Earth rotates and the Sun moves across the sky, a series of strong and weak signals is received by the antenna.

(b) As the Sun rises above the horizon in the morning, determine the largest value of the angle θ (smallest angle above the horizon) at which the **first** strong signal is observed. This strong signal is due to the constructive interference between the direct and reflected waves arriving at the antenna. Take the height of the antenna above the sea to be H = 85 m, and take into account the fact that the reflected radio wave undergoes a **phase change of 180°**.

θ for 1st strong signal = ……………… ° [2]

(c) Calculate the path difference between the rays reaching the antenna directly and those reaching the antenna after reflecting off the sea surface at noon when the Sun is directly overhead.

Path difference = ……………….. m [1]

(d) Determine the total number of strong signals received by the antenna between sunrise and noon, assuming that the Sun is directly above the antenna at noon.

Number of strong signals = ……………. [2]

[VJC 2015]

7(a) $v = f\lambda$

$$\lambda = \frac{v}{f} = \frac{3\times10^8}{20\times10^6} = \mathbf{15\ m}$$

7(b) For the first instance of constructive interference between the direct and reflected waves, path difference is equal to half a wavelength:

$$\Delta x = \frac{1}{2}\lambda$$

$$\therefore \Delta x = 2H\cos\theta = \frac{1}{2}\lambda$$

$$\therefore 2\times85\times\cos\theta = \frac{1}{2}\times15$$

$\therefore \cos\theta = 0.0441$ or $\theta = \mathbf{87.5^o}$

7(c) At noon, $\theta = 0^0$. Hence, the path difference is $\Delta x = 2H\cos 0^0 = 2H$
= 2 x 85 = **170 m.**

7(d) In general, for constructive interference between the direct and reflected waves, the condition required is:

$$\Delta x = \left(n - \frac{1}{2}\right)\lambda\ ,$$

where n = 1, 2, 3, …

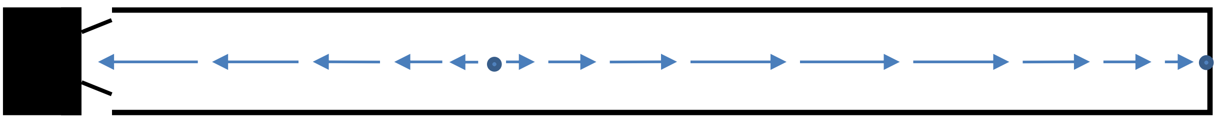
At noon, when the Sun directly above the antenna, the path difference = $2H = 2 \times 85 = 170$ m, which is equivalent to 170 / 15 = 11.3 wavelengths.
Hence, the last maximum obtained before noon occurs when $\Delta x = 10.5\,\lambda$.

$$\Delta x = \left(n - \frac{1}{2}\right)\lambda = 10.5\lambda$$

$\therefore$ $n = 11$.

Hence, a total of **11 strong signals** (instances of constructive interference) will occur between sunrise and noon.

8 A sound source is placed near the open end of a glass tube which is closed at the other end. The frequency *f* of the sound emitted by the source is varied. The arrows in Fig. 8.1a represent the movement of the air molecules in the glass tube in which a stationary longitudinal wave has been set up at a particular frequency *f*. The length of each arrow represents the amplitude of the motion, and the arrow head shows the direction of motion at a particular instant.



Sound source

Fig. 8.1a

Sound source

Fig. 8.1b

(a) On Fig. 8.1b, draw arrows to represent the displacement of the corresponding particles half a cycle later, indicating clearly positions of nodes with '**N**' and positions of antinodes with '**A**'. [2]

(b) Explain, by reference to the atmospheric pressure and the displacements of the particles, the pressure variation at the open end and the closed end of the tube. [2]

(c) A thin uniform layer of very dry cork dust was placed inside the tube along its entire length. Explain, by reference to the properties of stationary waves, why heaps of cork dust are formed at particular locations. [3]

(d) One frequency at which heaps are formed is 1.89 kHz. The distance between six heaps is measured to be 45.0 cm. Calculate *v*, the speed of sound in the tube. [2]

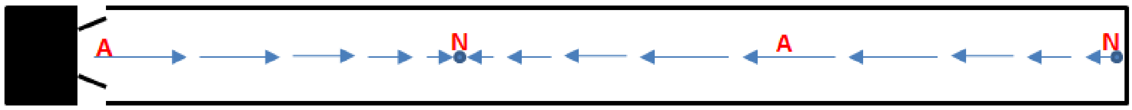
v = ... m s^{-1}

(e) Suggest a reason why the distance between six heaps was measured instead of measuring distance between two successive heaps. [1]

[HCI 2012 P3]

Question 8

(a)



A2

Mark by deduction
-1 for any mistake made in the particle movement, number and length of arrows
-1 for wrong labeling of N and A

(b)

Pressure variation is greatest at displacement nodes. Hence the closed end of the tube is subjected to large pressure changes from the atmospheric atmosphere. **B1**
Displacement antinodes correspond to points of pressure nodes. At the open end of the tube, particles are free to move about and hence the pressure remains at atmospheric pressure. **B1**

(c)

At suitable frequencies, a stationary sound wave is set up inside the tube.
At the displacement antinode positions, the amplitude is maximum. **B1**
The horizontal (longitudinal) oscillations sweep the dust to either side, thus there are no heaps settling at antinodes.
At the displacement node positions, the amplitude is zero. **B1**
Thus heaps of dust settles at the displacement nodes. **B1**

(d)

Distance between 6 nodes corresponds to 2.5λ,
$2.5\lambda = 0.450$ **M1**
$v = f\lambda = 1.89 \times 10^3\ (0.45/2.5) = 340\ \text{ms}^{-1}$ **A1**

(e)

The distance between successive dust heaps is difficult to measure accurately because the exact center of the dust heap cannot be ascertained definitely. However, a good average can be obtained by measuring the distance over a large number of dust heaps. **B1**

9 **(a)** Two coherent light wavetrains having the same plane of polarization meet at a point. State two conditions that must be fulfilled before totally destructive interference can occur. [2]

(b) Fig. 9.1 shows an experiment to demonstrate interference effects with microwaves. A transmitter, producing microwaves of wavelength λ, is placed in front of two slits separated by a distance a. A receiver is used to detect the strength of the resultant wave at different points along the line YZ which is at a distance D in front of the slits.

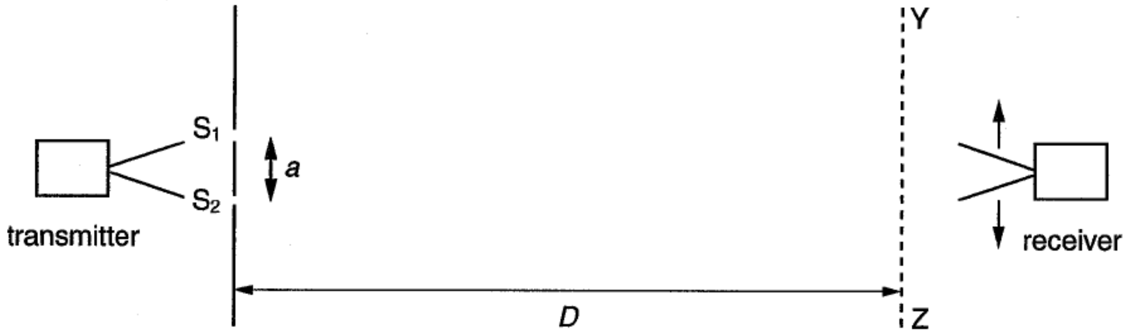


Fig. 9.1

(i) Explain, in terms of the path difference between the wavetrains emerging from the slits S_1 and S_2, why a series of interference maxima are produced along the line YZ. [2]

(ii) Predict how the distance x between neighbouring maxima on the line YZ would change if the distance a was doubled while the distance D was halved. [1]

(iii) Explain why it is necessary to use a barrier with two slits rather than two separate transmitters. [1]

(iv) In another experiment using the apparatus in Fig. 9.1, a student notices that the distances between the maxima are not equal. Suggest a reason for this difference. [1]

(v) Describe how you could test whether the microwaves leaving the transmitter were plane polarised. [2]

(c) The microwave transmitter is now placed in front of a plane reflector as shown in Fig. 9.2 and stationary waves are set up in the space between them.

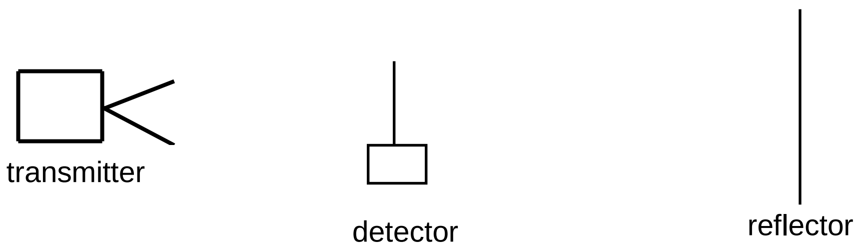


Fig. 9.2

A detector is moved between the transmitter and the reflector at a constant speed of 10 mm s^{-1}. The frequency of detection of minima is 1.5 Hz.

Determine the frequency of the microwave oscillator. [3]

frequency = ... Hz

[TJC 2013 P2]

9 **(a)** (Totally destructive interference means that the resultant wave has zero amplitude or waves cancel each other.)
Waves must meet π rad out of phase. [1]
Waves must have equal amplitude. [1]

(b) **(i)** Wavetrains from S_1 and S_2 are coherent and superpose at points along YZ. [1]
When path difference is an integral multiple of λ, the waves are in phase, constructive interference takes place to give a series of maxima. [1]

(iii) It decreased to one quarter of the original x (since $x = \lambda D/a$) [1]

(iii) So that the wavetrains are coherent. [1]

(iv) The line YZ is not parallel to the slits [1]
or the slits not normal to the (incident) microwaves

(v) Place a metal grid or polariser in front of the transmitter and rotate through 90° OR rotate transmitter/detector through 90°. [1]
If this causes minimal/zero signal at some angles, the wave is plane polarized. [1]

(c) Distance between two nodes = speed of detector / frequency of detection
= 10 / 1.5 = 6.7 mm [1]
Hence, wavelength = 13 mm [1]
f = c/λ = $3.00 \times 10^8 / 13 \times 10^{-3} = 2.3 \times 10^{10}$ Hz. [1]

10 (a) It is possible to use two separate oscillators feeding two loudspeakers to demonstrate interference of sound. It is not possible to use two filament lamps, however similar, to produce interference of light. Explain this difference. [1]

(b) Two identical loudspeakers are driven by the same oscillator of frequency 200 Hz. The loudspeakers are located on a vertical pole a distance of 4.00 m from each other.
A man walks straight towards the lower loudspeaker in a direction perpendicular to the pole as shown in Fig. 10.1.

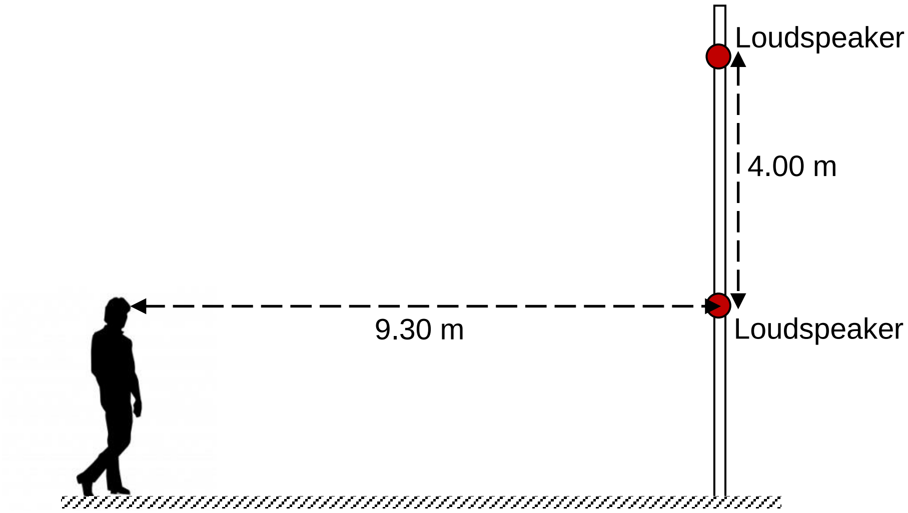


Fig. 10.1

(i) Determine whether the man will hear a minimum or a maximum in sound intensity when he is 9.30 m from the lower speaker.
(Take the speed of sound to be 330 m s^{-1} and ignore any sound reflection from the ground.) [3]

(ii) State two changes that can be made to the set-up in Fig 10.1 in order to increase the number of intensity fluctuations detected by the man as he walks towards the pole. [2]

10 (a) To obtain an observable interference pattern, the sources must be coherent. The two loudspeakers can be made coherent by connecting them to the same signal generator, but the two filament lamps can never be coherent sources since the light is produced in a random manner and there is no way to control the phase of the light waves emitted.

(b) **(i)** The distance of the upper loudspeaker from the man is $\sqrt{9.30^2 + 4.00^2} = 10.124\text{ m}$

$\therefore$ the path difference between the waves reaching the man is $10.124 - 9.30 = 0.8237\text{ m}$

The wavelength $\lambda = \dfrac{330}{200} = 1.65\text{ m}$,

$\therefore$ the path difference is $\dfrac{0.8237}{1.65} = 0.5\lambda$

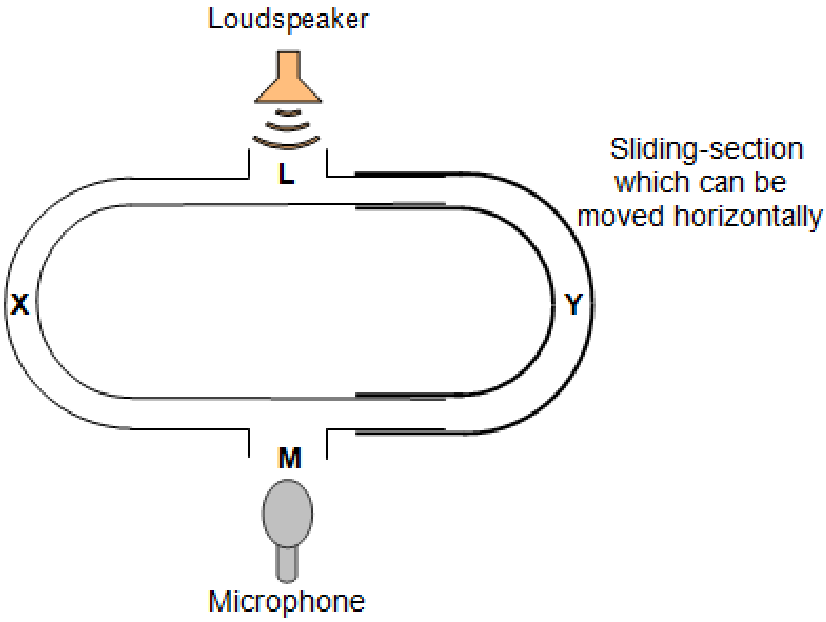
This means that the waves interfere destructively and the man will hence detect a minimum of sound intensity.

(ii) Two changes to the set-up that can be made are:

1. Increase the frequency of the sound
2. Increase the separation between the two loudspeakers

11 **(a)** State the *principle of superposition*.. [2]

(b) Sound produced by the loudspeaker shown below has a frequency of 4.0×10^3 Hz. The sound waves arrive at the microphone M via two different paths, LXM and LYM. The left-tube is fixed in position, while the right-tube is a sliding-section. At position M, the sound waves from the two paths interfere.



Initially, the lengths of paths LXM and LYM are equal. The sliding-section is then pulled out horizontally to the right by a distance of 0.020 m, and the loudness at microphone M changes from a maximum to a minimum.

(i) Determine the path difference between the two waves after the sliding-section is pulled out. [1]

path difference = ... m

(ii) Calculate the speed at which sound travels through the tubes. [2]

speed = ... m s^{-1}

(ii) When the opening at M is sealed, explain why a standing wave can be set up in the tube. [3]

[PJC 2013 P2]

11(a) The principle of superposition states that when two or more travelling waves of the same type meet at a point in space, the resultant displacement at that point is the vector sum of the displacements that the waves would separately produce at that point.

11(b)(i) Path difference $= 2 \times 0.020$
$= 0.040$ m

11(b)(ii) Path difference $= \dfrac{\lambda}{2}$

$\lambda = 2 \times 0.040$
$= 0.080$ m

$v = f\lambda$
$= 4000\ (0.080)$
$= 320$ ms^{-1}

11(b)(iii) The sound waves from path LXM and LYM travel in the opposite directions and meet.

Since both waves are of equal amplitude, frequency and speed, they superpose and interfere to form a stationary wave.

12 Two sources $\mathbf{S_1}$ and $\mathbf{S_2}$ operate in phase to produce circular waves as shown in Fig. 12.1. (Note that the circles represent crests.)

Along the line **XY**, there is a series of alternate maxima and minima.

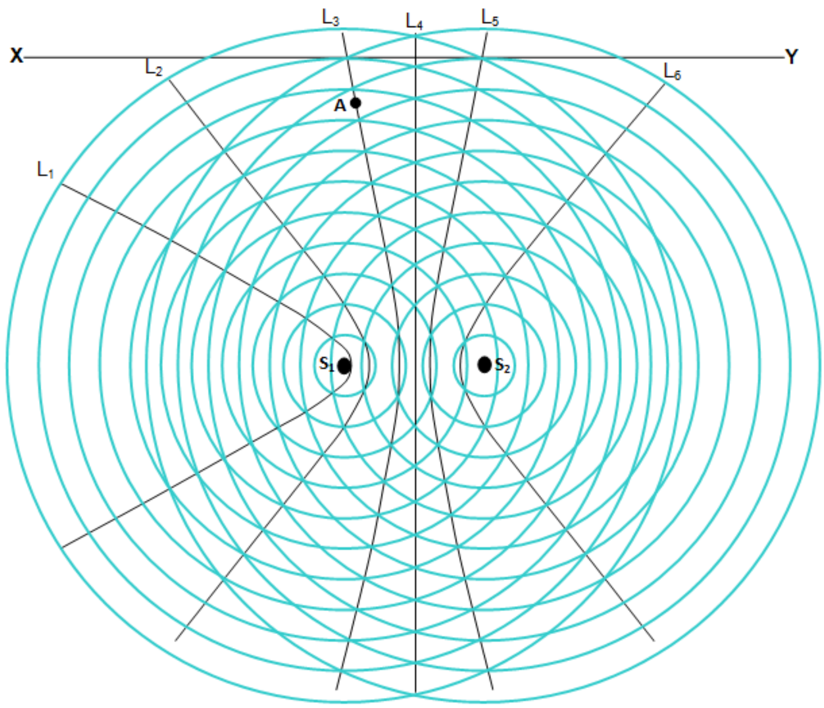


Fig. 12.1

(a) Explain what lines L_1 to L_6 represent and whether point **A**, as indicated in Fig. 12.1, is a point of constructive or destructive interference. [2]

(b) State the relationship between the magnitude of the path difference $S_1P - S_2P$ and wavelength, for any point P on the lines L_1 to L_6. [1]

(c) Hence state, in terms of wavelength, the path difference for point A. [1]

path difference = ...

(d) Draw, on Fig. 12.1, a line to show one direction along which the waves have minimum amplitude. [1]

(e) Determine the number of directions between lines $\mathbf{L_1}$ and $\mathbf{L_6}$ along which maximum amplitude occurs (excluding L_1 and L_6). [1]

number of directions = ...

(f) Determine the number of directions between lines $\mathbf{L_1}$ and $\mathbf{L_6}$ along which maximum amplitude occurs (excluding L_1 and L_6). [1]

12

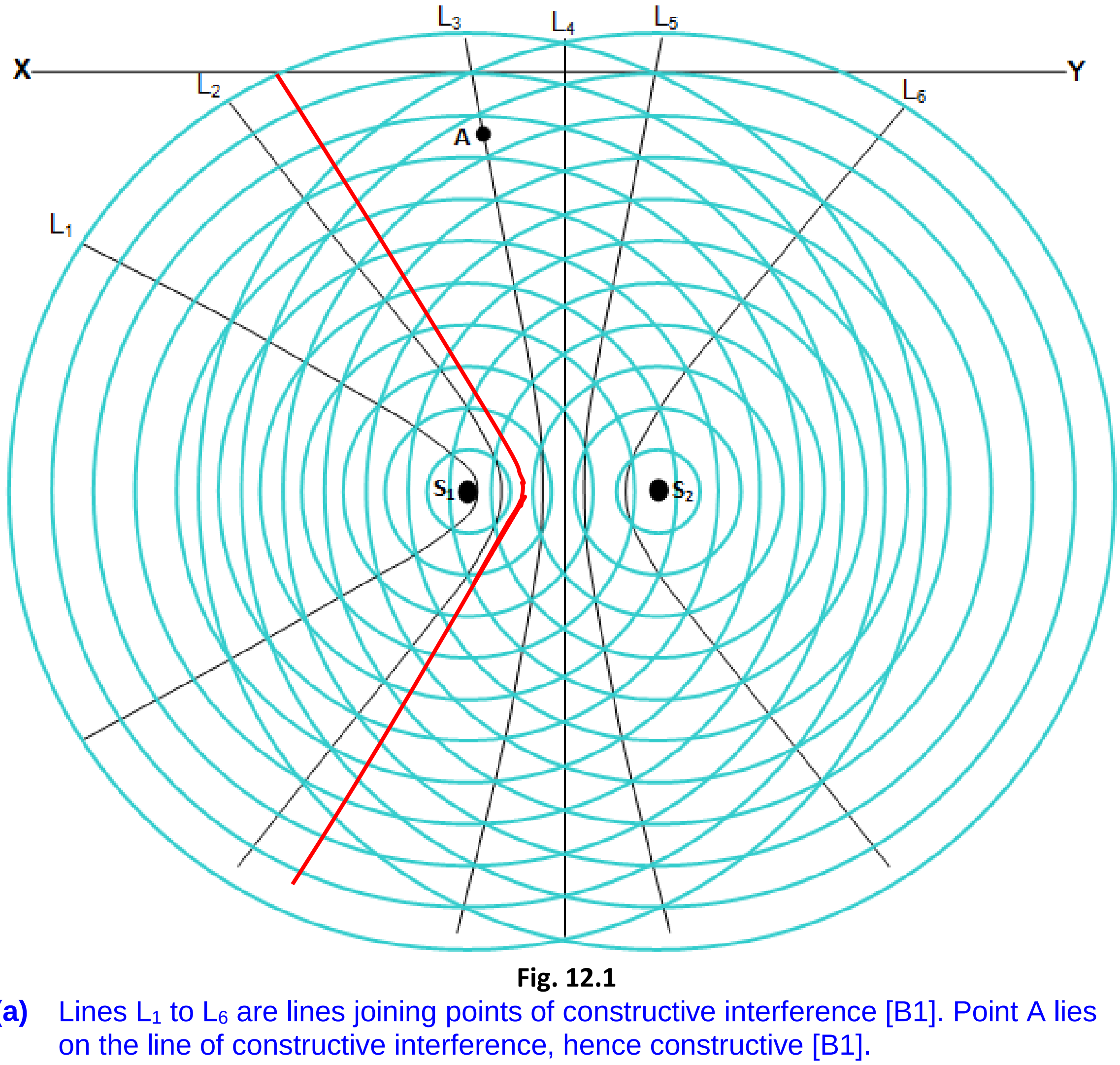


Fig. 12.1

(a) Lines L_1 to L_6 are lines joining points of constructive interference [B1]. Point A lies on the line of constructive interference, hence constructive [B1].

(b) Path difference $\mathbf{S_1P - S_2P}$ is equal to integer multiple of wavelength i.e. $\mathbf{S_1P - S_2P = n}\,\lambda$ [A1] where n = 0, 1,2,3 …

(c) Path difference $\mathbf{S_1A - S_2A}$ is equal to one wavelength [A1].

(d) see

(e) 6

(f) Spacing decreases (similar to double slit formula) [A1]

13 **(a)** State what is meant by the diffraction of a wave. [1]

(b) A laser produces a narrow beam of coherent light of wavelength 632 nm. The beam is incident normally on a diffraction grating, as shown in Fig. 13.1.

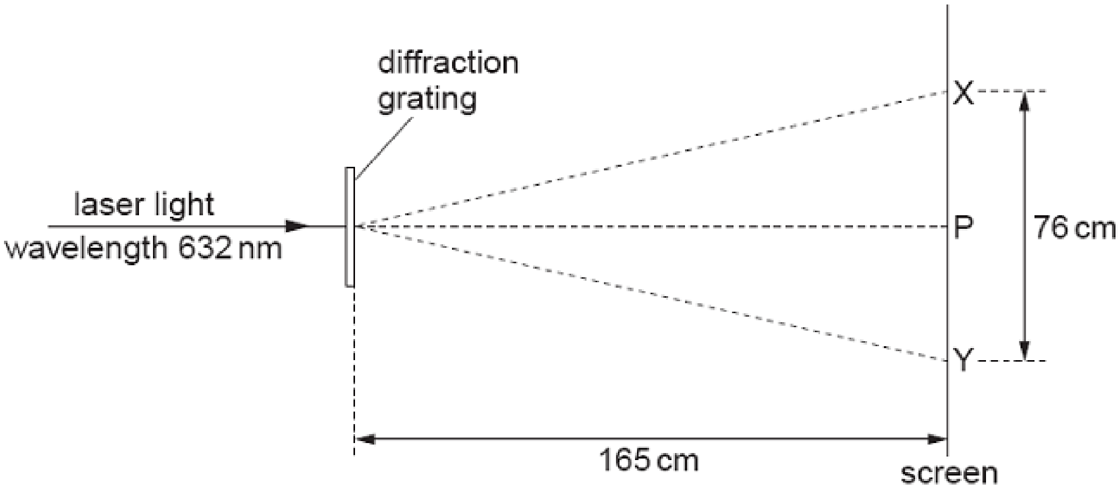


Fig. 13.1

Spots of light are observed on a screen placed parallel to the grating. The distance between the grating and the screen is 165 cm. The brightest spot is P. The spots formed closest to P and on each side of P are X and Y. X and Y are separated by a distance of 76 cm.

Calculate the number of lines per millimetre on the grating. [3]

Number of millimetre = ...

(c) The grating in **(b)** is now rotated about an axis parallel to the incident laser beam, as shown in Fig. 13.2.

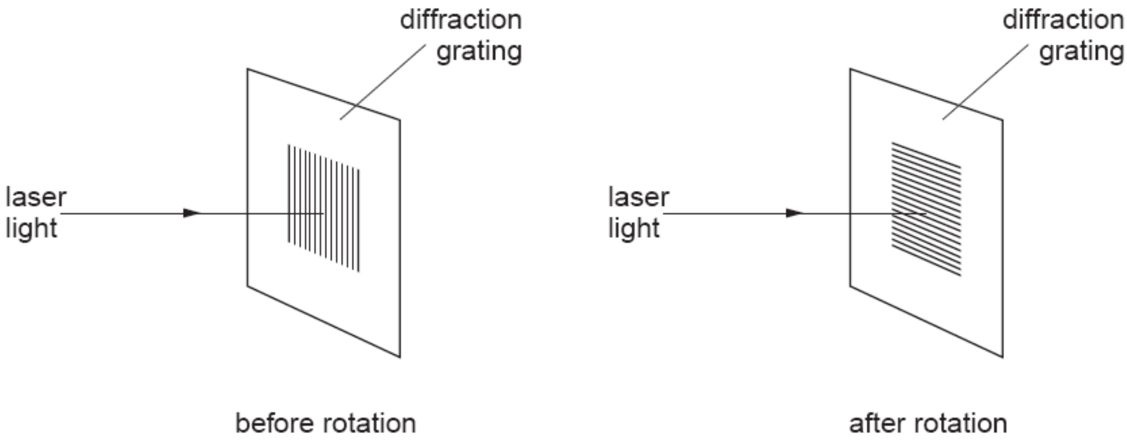


Fig. 13.2

State what effect, if any, this rotation will have on the positions of the spots P, X and Y. [2]

(d) In another experiment using the apparatus in **(b)**, a student notices that the distances XP and PY, as shown in Fig. 13.1, are not equal. Suggest a reason for this difference. [1]

[AJC 2013 P2]

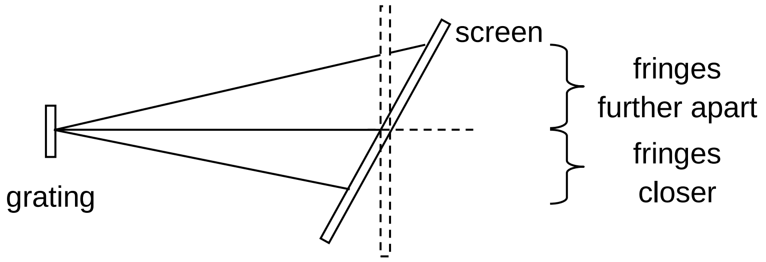
13 **(a)** Diffraction is the spreading of waves when they pass through an opening or round an obstacle.

(b) $\tan\theta = 38/165$
$\theta = 12.99°$
$d \sin\theta = \lambda$
$d = 2.82 \times 10^{-6}$ m
no of lines per mm = 1/d
= 360

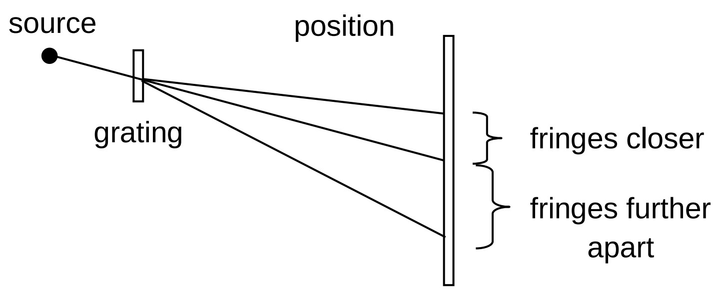
(c) P remains in same position
X and Y rotate through 90° about P

(d) Either 1. screen not parallel to grating, OR
2. grating not normal to (incident) light

1.



2.



14 **(a)** One end of a string is attached to a wall. A student creates a **single** pulse in the string that travels to the right as shown in Fig. 14.1.

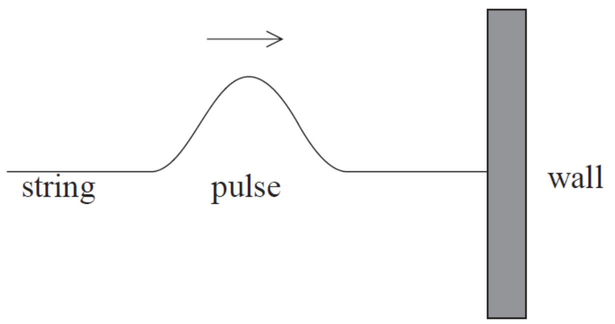


Fig. 14.1

(i) On Fig. 14.1, sketch the shape and size of the pulse after it has been reflected from the wall. [1]

(ii) By reference to Newton's third law, explain your sketch in **(a)(i)**. [2]

(b) The apparatus illustrated in Fig. 14.2 is used to demonstrate two source interference using light.

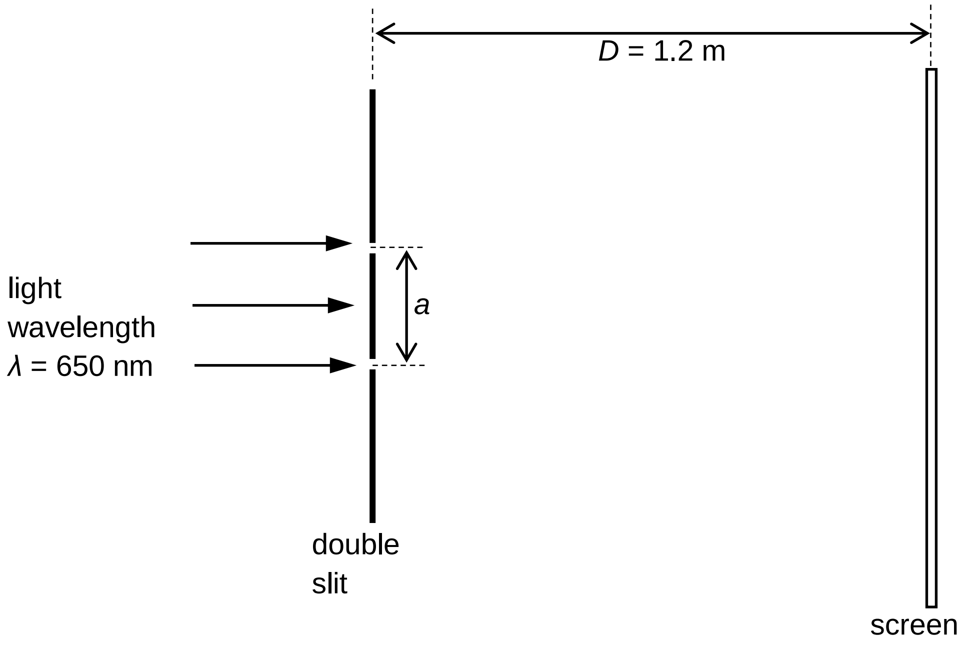


Fig. 14.2 (not to scale)

Light of wavelength λ = 650 nm is incident normally on the double slit arrangement. The interference fringes formed are viewed on a screen placed parallel to the plane of the double slit with D = 1.2 m. The slit separation is 1.1 mm.

(i) Calculate the separation of the fringes.

separation = ………………………………. mm [2]

(ii) State the effect, if any, on the separation and intensity of the fringes observed on the screen when the following changes are made, separately, to the double slit arrangement.

1. The width of each slit is increased but the slit separation remains constant. [2]

2. Light is incident at a small angle to the normal of the plane of the double slit as shown in Fig. 14.3. [2]

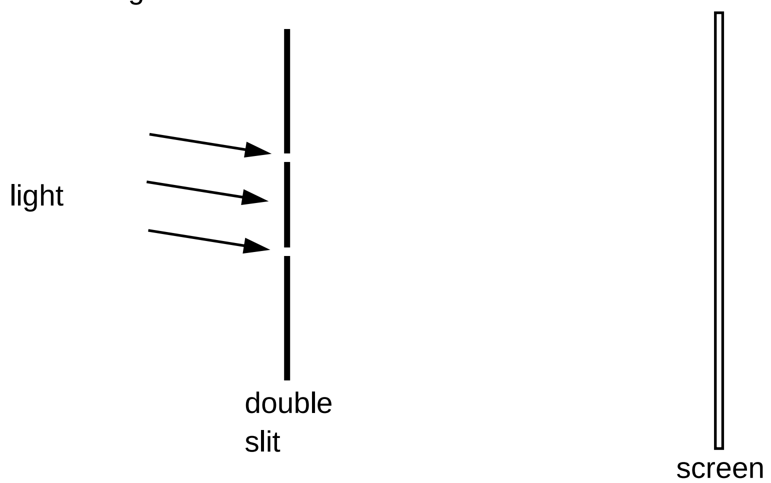


Fig. 14.3 (not to scale)

[DHS 2015]

14	**(a)**	**(i)**	Pulse of similar shape and inverted.	B1	[1]
		(ii)	The string exerts an <u>upward</u> force on the wall, and	M1	
			the wall exerts a <u>downward</u> force on the string by N3L,	M1	
			creating an inverted pulse.	A0	[2]
	(b)	**(i)**	$x = \lambda D/a$		
			$= (650 \times 10^{-9})(1.2) / (1.1 \times 10^{-3})$	M1	
			$= 0.71$ mm	A1	[2]
		(ii)1	Same separation	B1	
			Bright areas brighter but dark areas no change	B1	[2]
			(note: fewer fringes observed)		
		2	Same separation	B1	
			Same brightness for fringes	B1	[2]
			(note: locations of the bright fringes will change, depend on the phase difference between the waves coming from both slits)		

Long Structured Questions

1 **(a)** Fig. 1.1 shows the variation of displacement with position at a particular instant for a progressive sound wave travelling in air

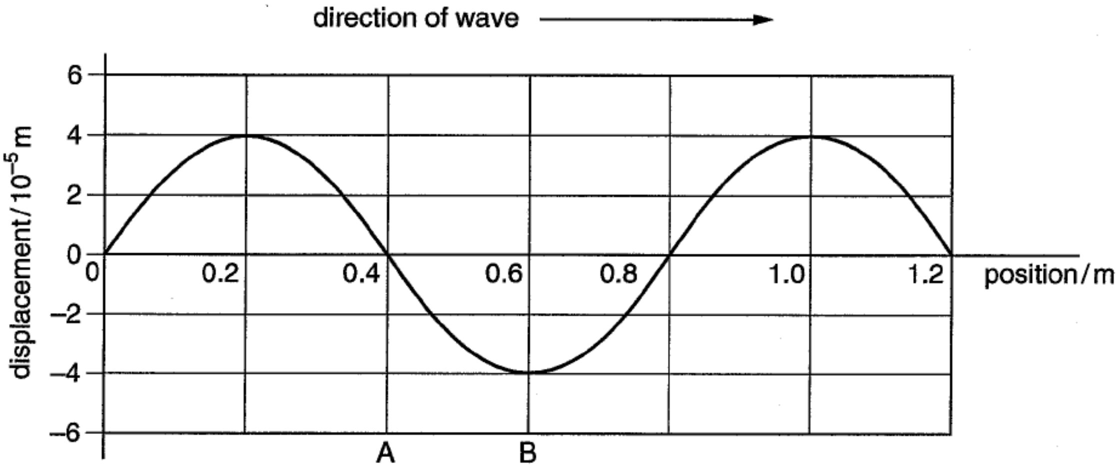


Fig. 1.1

(i) An air particle at position A vibrates with simple harmonic motion. State the general conditions necessary for simple harmonic motion. [2]

(ii) Describe the motion of the air particle at position A as one full cycle of the wave passes. [3]

(iii) State one way in which the motion of an air particle at position B is similar to, and one way in which it is different from, the motion of an air particle at A as the wave passes. [2]

(iv) The speed of the sound wave is 340 m s^{-1}. Calculate the frequency of the sound. [1]

frequency = ... Hz

(b) Fig. 1.2 shows a laboratory microwave transmitter T positioned directly opposite a microwave detector D which is connected to a meter.

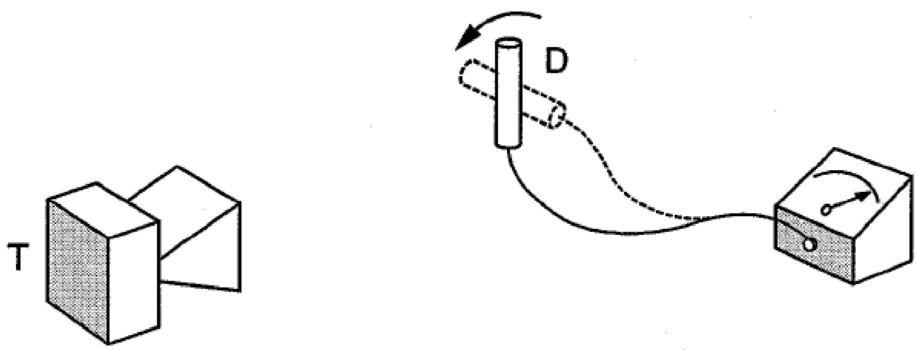


Fig. 1.2

Initially the meter shows a maximum reading. When the detector is rotated through 90°, in vertical plane as shown, the meter reading falls to zero.

(i) Explain why the meter reading falls. [2]

(ii) Predict what would happen to the meter reading if the detector were rotated through a further 90°. [1]

(iii) State what the observations tell you about the nature of microwaves. [1]

(c) Fig. 1.3 is a plan view of the same arrangement shown in Fig 1.2 with the addition of a metal plate M placed in front of the transmitter. The plate M contains a double slit.

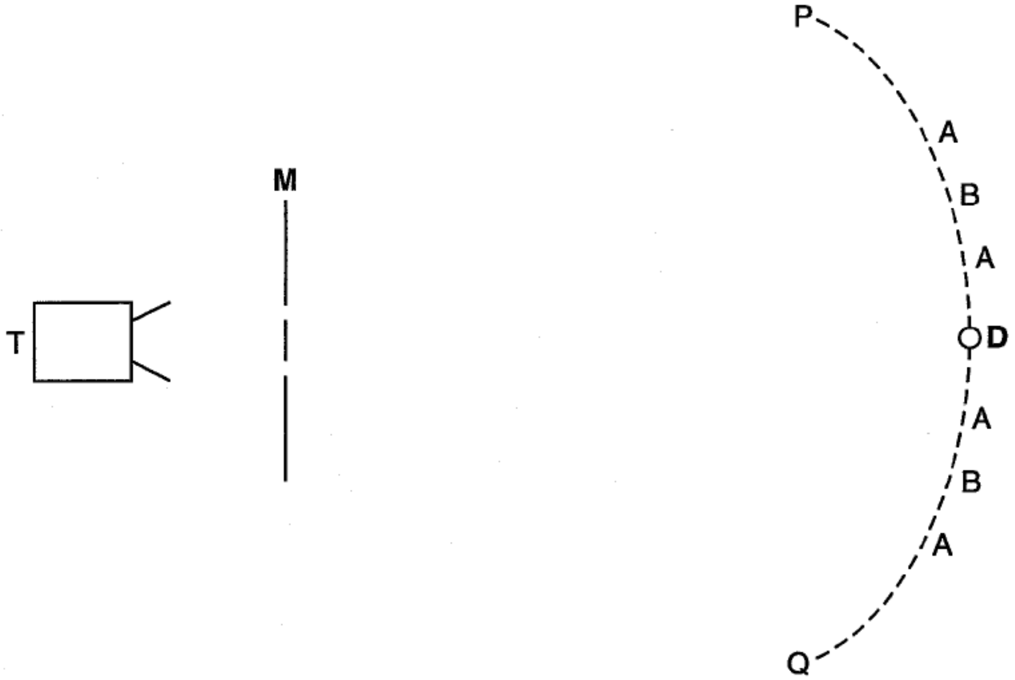


Fig. 1.3

When the detector D is placed in the position shown, the meter reading is a maximum, but as it moves along the horizontal arc PQ the reading passes through a sequence of low and high readings at positions A and B respectively.

(i) State the name of the phenomenon that accounts for this. [1]

(ii) Explain why the meter reading is a maximum when the detector is in the position shown (i.e. directly opposite the centre of the double slit). [1]

(iii) Explain why
1. the meter reading is low at positions A. [1]

2. the meter reading is high at positions B. [1]

(iv) Suggest, with reasons, how the total number of low and high readings along the arc PQ changes when the separation between the slits in M is reduced. [2]

(v) Explain why it is necessary to use a barrier with two slits rather than two separate transmitters in the arrangement shown in Fig. 1.3 [1]

[AJC 2013 P3]

1 **(a)** **(i)** The acceleration (or force) of a particle is proportional to displacement from the equilibrium position / fixed point
and acceleration (or force) is always directed towards that fixed point / in opposite direction to displacement

(ii) Air particle vibrates in the <u>same</u> direction as the propagation of wave.
(allow left to right, backwards and forwards, but NOT up and down)

Air particle at equilibrium position having maximum velocity moves to the <u>right (or left)</u> with deceasing velocity, <u>momentary at rest at amplitude position</u>, <u>changing direction</u> and moves towards the equilibrium position with increasing velocity, reaches equilibrium position and <u>continues to move to the left (or right) with decreasing velocity towards the other amplitude position</u>; <u>momentary at rest at amplitude position</u>, <u>changing direction</u> and moves to the right (or left) towards the equilibrium position with increasing velocity.

(iii) similarity: both have same amplitude/frequency/period
difference: phase difference of $\pi/2$ rad or movements is 90° out of phase

(iv) Wavelength λ = 0.8 m
$v = f\lambda$
$f = v/\lambda$
$= 340/0.8 = 430$ Hz

(b) **(i)** (transmitter emits) microwaves that are (vertically plane) <u>polarised</u>
Detector only detect waves (polarised) <u>parallel</u> to it

(ii) reading increases from zero to a maximum reading

(iii) microwaves are transverse

(c) **(i)** Interference

(ii) <u>Equal distance</u> travelled by waves from both slits (or <u>zero path diff),</u> waves meet in phase and hence constructive interference occurs

(iii) **1.** Low reading at A because path difference is an odd number of $\lambda/2$, i.e. $\lambda/2$, $3\lambda/2$, $5\lambda/2$….., wave arrives 180° out of phase and destructive interference occurs.

2. High reading at B because path difference is a whole number of λ, i.e. λ, 2λ, 3λ…. but not zero, waves meet in phase and constructive interference occurs.

(iv) since $x = \lambda D/a$ where x is the fringe spacing, a is the separation of the slits, D is the distance of the detector from the slits and λ is the wavelength of microwave.
and $x \propto 1/a$ if D and λ are the same.
<u>Hence fewer</u> (highs and lows) or <u>more spread</u> out (highs and lows)

(v) Waves must be coherent for interference to occur
Two transmitters would not be coherent / two slits in front of a transmitter create coherent sources

2 A magnet is suspended vertically from a fixed point by means of a spring, as shown in Fig. 2.1.

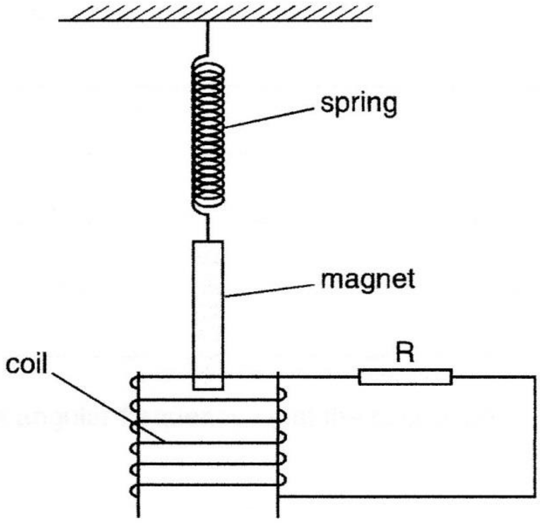


Fig. 2.1

One end of the magnet hangs inside a coil of wire. The coil is connected in series with a resistor R.

(a) The magnet is displaced vertically downward a small distance D and then released. Fig. 6.2 shows the variation with time t of the vertical displacement d of the magnet from its equilibrium position.

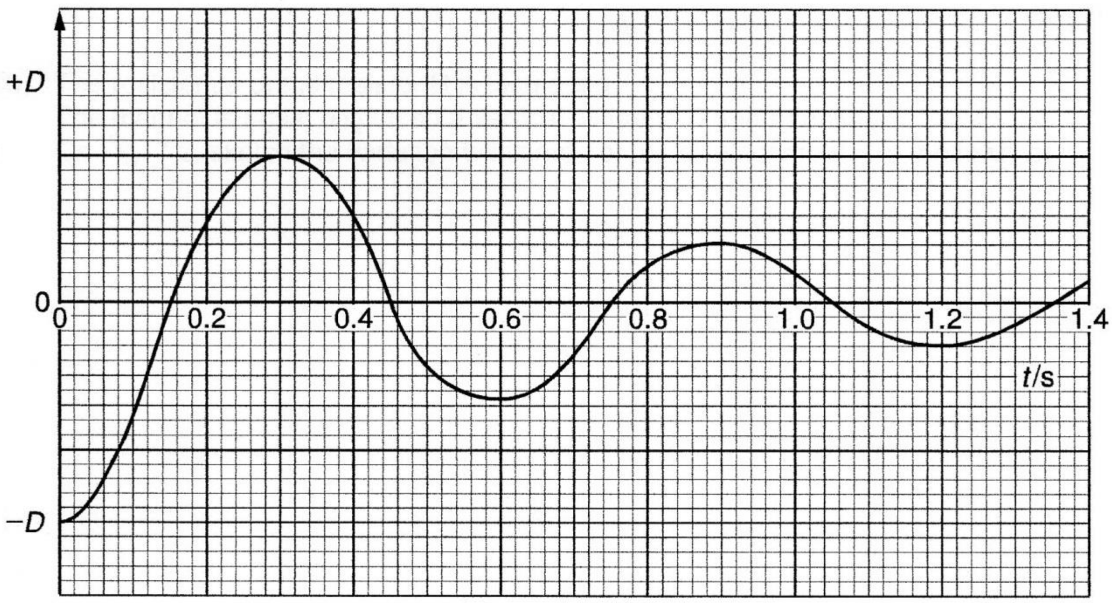


Fig. 2.2

(i) State and explain, by reference to the laws of electromagnetic induction, the nature of the oscillations of the magnet. [4]

(ii) Calculate the angular frequency ω_0 of the oscillations. [2]

angular frequency = ... rad s^{-1}

(iii) Determine the magnitude, in terms of D, and the direction of the acceleration of the magnet at t = 0.40 s. [3]

(iv) The magnet experiences a mean damping force of 2.5 N. Calculate the average power needed to be supplied to the magnet to keep it oscillating with a constant amplitude D where D = 15 mm. [2]

power = ... W

(b) The magnet is again displaced a vertical distance D and released. On Fig. 2.2, sketch the variation with time t of the displacement d of the magnet. [2]

(c) The resistor R in Fig. 2.1 is replaced by a variable-frequency signal generator of constant r.m.s. output voltage. The angular frequency ω of the generator is gradually increased from about $0.7\omega_0$ to about $1.3\omega_0$, where ω_0 is the angular frequency calculated in **(a)(ii)**.

(i) On the axes of Fig. 2.3, sketch a graph to show the variation with ω of the amplitude A of the oscillations of the magnet. [2]

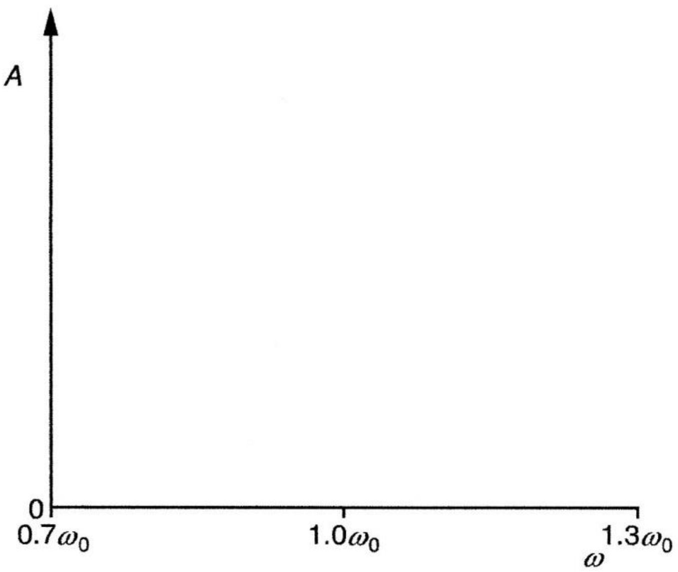


Fig. 2.3

(ii) State the name of the phenomenon illustrated in the graph of Fig. 2.3. [1]

(iii) Briefly describe one situation where the phenomenon named in **(ii)** is useful and one situation where it is a problem or nuisance. For each example identify what is oscillating and what causes these oscillations [2]

[TJC 2013 P3]

2 (a) (i) The oscillations of the magnet are lightly damped. The amplitude decreases with time. [1] As the magnet moves, magnetic flux is cut by the coil. From Faraday's law, an e.m.f. is induced in the coil. [1] Since the circuit is closed, a current flows. [1]
From Lenz's law, the induced current produces a magnetic force on the magnet opposing its motion. [1]
(<u>OR</u> From Lenz's law, the electrical energy, which is dissipated in the load as heat, is derived from the mechanical energy of the magnet.)

(ii) T = 0.60 s (2 d.p.) [1]

$\omega_0 = \dfrac{2\pi}{T} = \dfrac{2\pi}{0.60}$ = 10.5 rad s^{-1} [1]

(iii) $a = \omega_0^2 x = (10.5)^2 \times \dfrac{6}{15} D = 44\,D$ [2]

direction of a: downward [1]

(iv) initial total energy $E_i = ½\, m\omega_0^2 D^2$

at t = 1.2 s, total energy $E_f = ½\, m\omega_0^2 \left(\dfrac{3}{15} D\right)^2$ [1]

$$\therefore \text{ fraction } = \frac{\Delta E}{E} = \frac{E_i - E_f}{E_i} = 1 - \frac{E_f}{E_i} = 1 - \left(\frac{D_f}{D_i}\right)^2 = 1 - \left(\frac{3}{15}\right)^2 = 0.96$$ [1]

(v) Work done W = mean force × distance moved

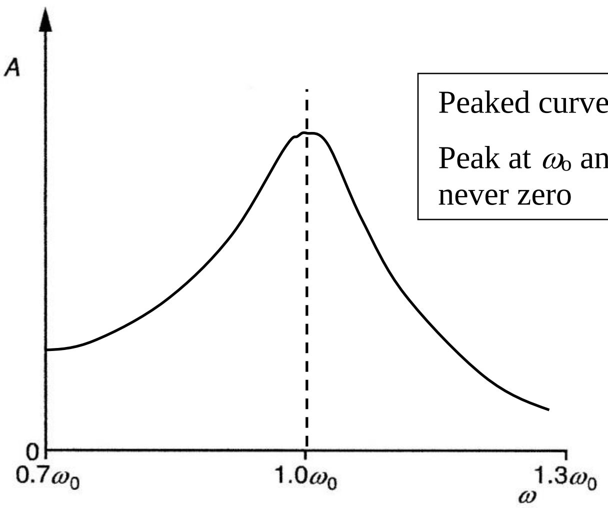
For ¼ oscillation, distance moved = 15 × 10^{-3} m

Average power = W / t = 2.5 × 15 × 10^{-3} / (0.60/4) = 0.25 W [2]

(b) less damping

larger amplitude [1] with period unchanged [1]

(c) **(i)**



Peaked curve [1]

Peak at ω_0 and amplitude never zero [1]

(ii) Resonance [1]

(iii) <u>Useful</u> [1]

Cooking: microwaves cause water molecules to resonate thereby heating food

MRI: radio waves (in a magnetic field) cause nuclei/proton to resonate

Person on swing: intermittent pushes cause swing to go higher

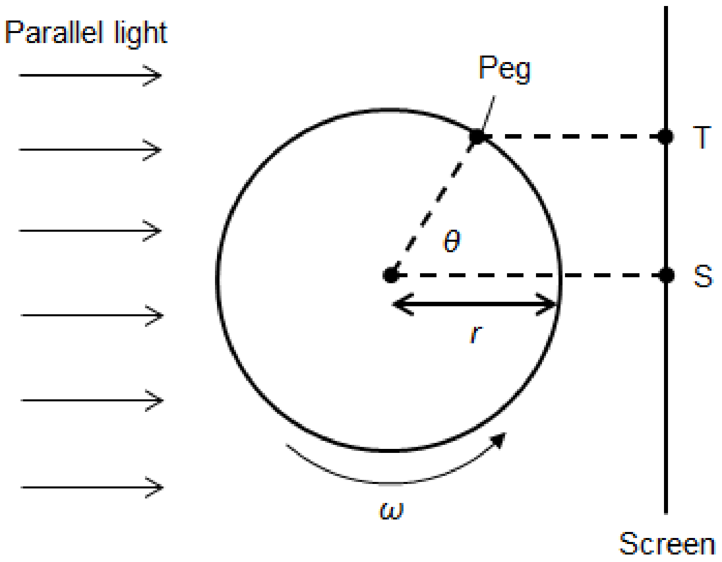
<u>Problem</u> [1]

Bridges: wind/walking in step causes bridge to resonate

Vehicles: engine vibrations cause panels/mirrors to resonate

Earthquakes: ground vibrating causes buildings to resonate

3 **(a)** A vertical peg is fixed to the rim of a horizontal turntable of radius r = 15.0 cm, rotating with a constant angular speed ω = 4.0 rad s^{-1}, as shown in Fig. 3.1 below.



Parallel light is incident on the turntable so that the shadow of the peg is observed on a screen, which is normal to the incident light. At time t = 0, θ = 0 and the shadow of the peg is seen at **S**.

At some later time t, the shadow is seen at **T**.

(i) Write down an expression for the angular displacement θ in terms of ω and t. [1]

(ii) Derive an expression for the distance **ST** in terms of r, ω and t. [1]

(iii) By reference to your answer in **(a)(ii)**, derive how the acceleration of the shadow changes with its vertical displacement. Hence describe the motion executed by the shadow on the screen. [2]

(iv) Calculate the period of the motion of the shadow on the screen. [1]

period = ... s

(v) Hence, or otherwise, calculate the speed of the shadow as it passed through **S**.[2]

speed = ... m s^{-1}

(v) The peg is shifted inwards on the horizontal turntable to a smaller radius. State and explain the changes to the answers in **(iv)** and **(v)** for the motion of the shadow on the screen. [2]

1. Period

2. Speed

(b) A block P of mass 80 g is attached to the free end of a horizontal spring on a smooth surface. The spring-mass system is set into simple harmonic motion by pulling P to the right of the equilibrium position and is released from rest as shown in Fig. 3.2.

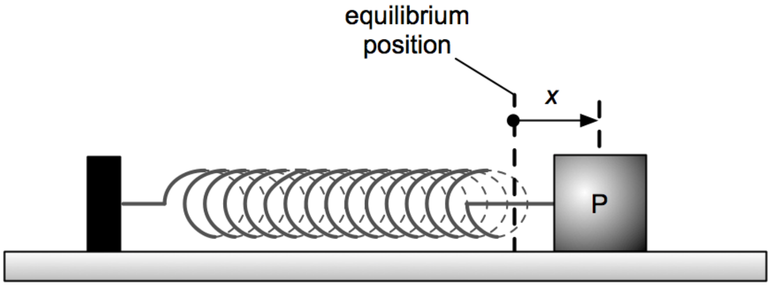


Fig. 3.2

If the air resistance on P is negligible, the variation of the velocity v of P with displacement x is shown in Fig. 3.3. Vectors to the right are taken to be positive.

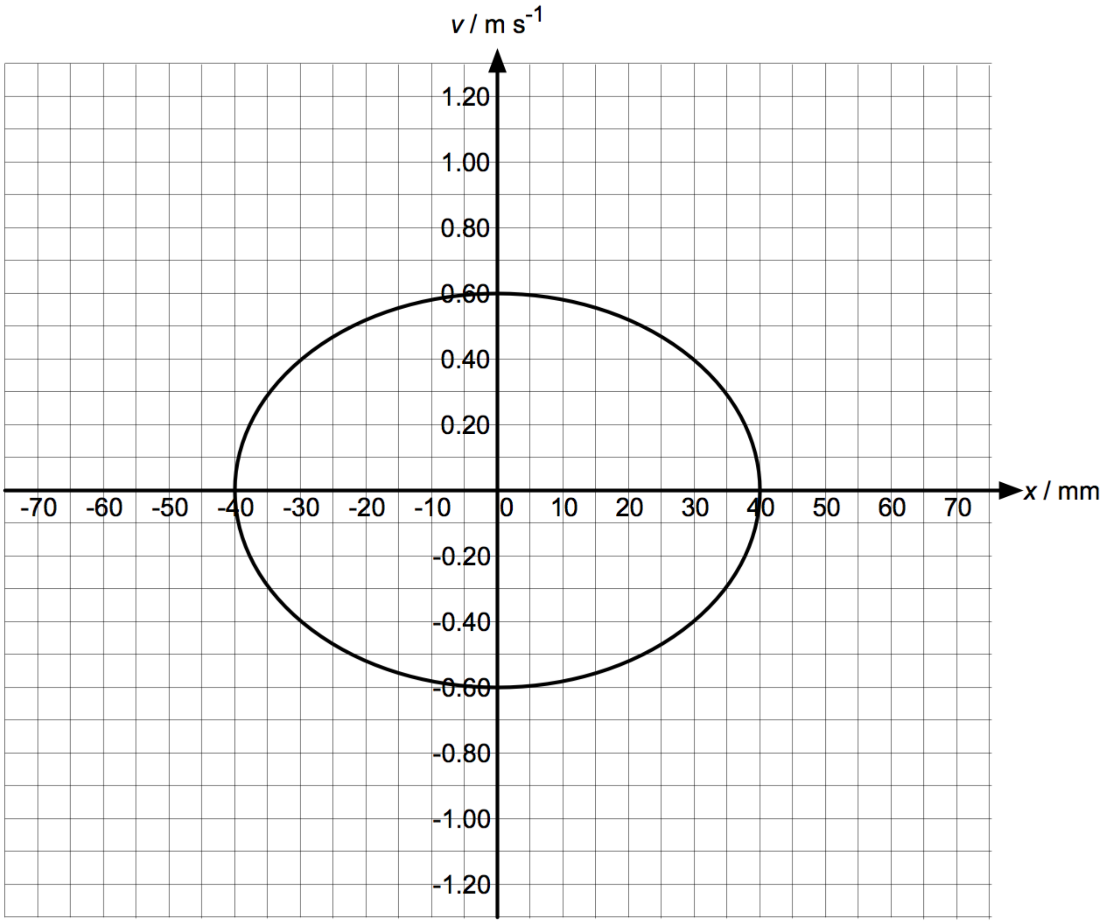


Fig. 3.3

(i) Calculate the maximum force acting on P. Write down a possible position where P experiences maximum force. [3]

maximum force = ... N

(ii) If the air resistance on P is not negligible, sketch on Fig. 3.3 a possible variation of the velocity of P with displacement *x*. [2]

(iii) A periodic force is now exerted on the spring-mass system. When the periodic force is at a certain frequency, P is in resonance.
1. Explain what is meant by the term resonance. [1]

2. Using energy consideration, explain why the total energy of the system increases to another value at steady state. [2]

3. Given that the final total energy of the spring-mass system at steady state is doubled, determine the new amplitude of P. [3]

amplitude = ... m
[HCI 2013 P3]

3 (a) (i) $\theta = \omega t$ 1

(ii) $ST = r\sin\theta$

$ST = r\sin\omega t$ 1

(iii) Let $x = ST = r\sin\omega t$

$v = r\omega\cos\omega t$

$a = -r\omega^2\sin\omega t$

$= -\omega^2 x$ 1

The motion of the shadow is simple harmonic vertically about point S. 1
(the second mark is only awarded if student successfully derive and show how the acceleration of the shadow changes with its vertical displacement)

(iv) $T = \dfrac{2\pi}{\omega} = \dfrac{2\pi}{4.0} = 1.57\text{ s}$ 1

(v) As the shadow passes S, speed of shadow = speed of peg.

$v = r\omega = (15.0\times10^{-2})(4.0)$ 1

$v = 0.60\text{ m s}^{-1}$ 1

(vi)
1. Period remains unchanged as ω remains the same. 1
2. Speed decreases as amplitude of the SHM decreases while ω remains the same. 1
   Or the peg has to move a smaller distance along the arc for the same period of time.

(b) (i) P experiences maximum force when x = 40 mm or -40 mm. 1

Method 1:

$$F_{max} = ma_{max} = m\omega^2 x_o = m\left(\frac{v_0}{x_0}\right)^2 x_0$$

$$F_{max} = \frac{0.080(0.60)^2}{4.0\times10^{-2}}$$ 1

$$F_{max} = 0.72N$$ 1

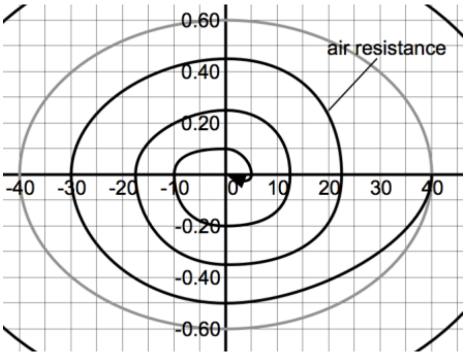
Method 2:

$$KE_{max} = \frac{1}{2}mv_0^2 = \frac{1}{2}(0.080)(0.60)^2 = 0.0144\,J$$

$$EPE_{max} = \frac{1}{2}kx_o^2 \quad \Rightarrow \quad k = \frac{2(KE_{max})}{x_o^2} = 18$$

$$F_{max} = kx_o = 18(0.04) = 0.72N$$

(ii)



- Spiral inwards 1
- Start at 40 mm and clockwise direction 1
  [question given states that P is pulled to the right (positive x from diagram) and released, so upon release, P moves leftwards so the velocity has to be negative.]

(iii) 1. When the frequency of the periodic driving force is the same as the natural frequency of the system, the amplitude of the system is at its maximum. 1

2. The periodic force is transferring energy to the oscillating system / work is done on the system so the total energy of the system increases. 1
When the rate of energy transfer is equal to the energy lost due to resistance, the total energy reaches a steady value. 1

3. $$E_T = \frac{1}{2}mv_0^{\,2} = \tfrac{1}{2}m\omega^2 x_0^{\,2} \Rightarrow E_T \propto x_0^{\,2}$$ 1

$$\frac{E_T'}{E_T} = \frac{x_0^{\,2}}{x_0^{\,2}} \Rightarrow \frac{2E_T}{E_T} = \frac{x_0^{\,2}}{0.040^2}$$ 1

$$x_0 = 0.056 \text{ m}$$ 1

4 **(a)** State the Principle of Superposition [2]

(b) Describe the conditions necessary for observable two-source interference fringes to be formed.

…………………………………………………………………………………………………..… [2]

(c) Two microwaves emitters, placed a distance of 2*d* apart at P and Q, operate with the same power and produce waves of the same frequency. The line OX is equidistant from both sources while points Y and Z are equidistant from O and line YXZ is perpendicular to OX, as shown in Fig. 4.1.

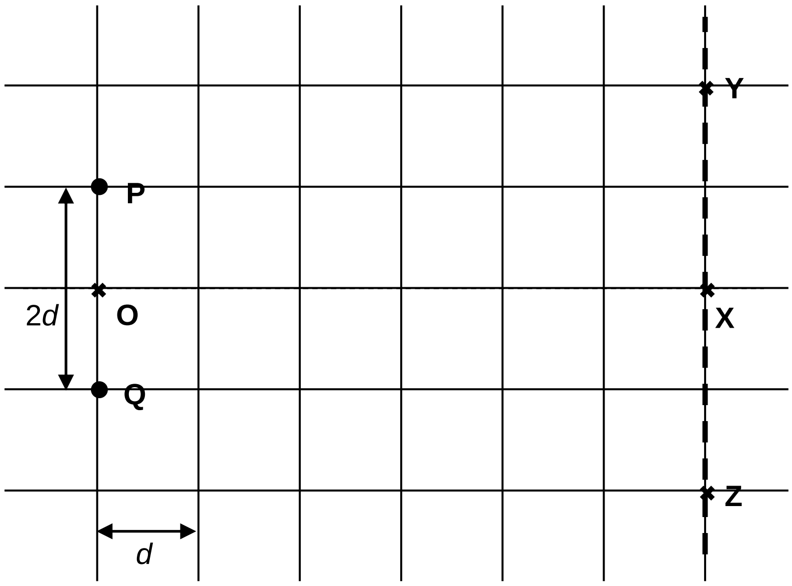


Fig. 4.1

(i) The electric-field component of the microwaves from P and Q arriving at point Y are seen to vary with time as shown in Fig. 4.2.

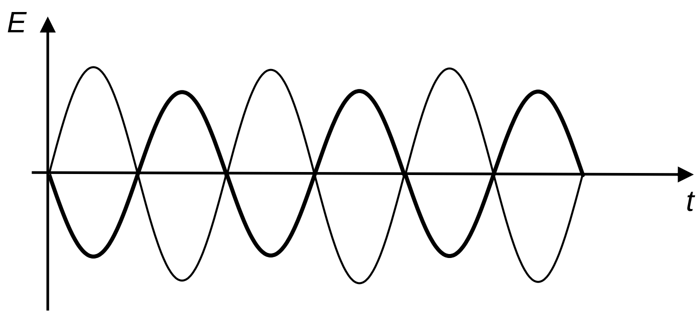


Fig. 4.2

1. On Fig. 4.2, label clearly the waveforms with “P” and “Q” to indicate their origins. [1]

2. State and explain if the waves arriving at Y are coherent.

[1]

(ii) Show that the path difference in the waves arriving at point Y, is 0.625*d*.

[1]

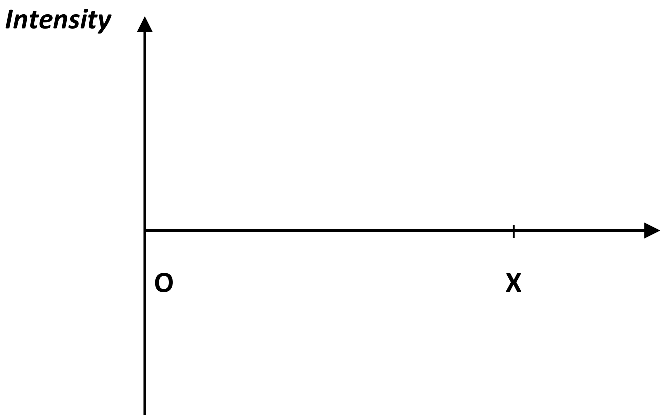
(iii) As a detector is moved in a straight line from X to Y, it encountered three intensity maxima including the one at X. Find the frequency of the wave in terms of *d*.

frequency = …………………….. [3]

(iv) The distance between grid-lines, *d*, was measured to a percentage uncertainty of 2%. Determine the percentage uncertainty in the value of frequency obtained in part **(iii)**.

percentage uncertainty = …………………% [1]

(v) The detector is now moved along the line OX instead. Sketch how the intensity measured will vary along OX.



[2]

(d) Fig. 4.3 shows how the intensity varies along line YZ.

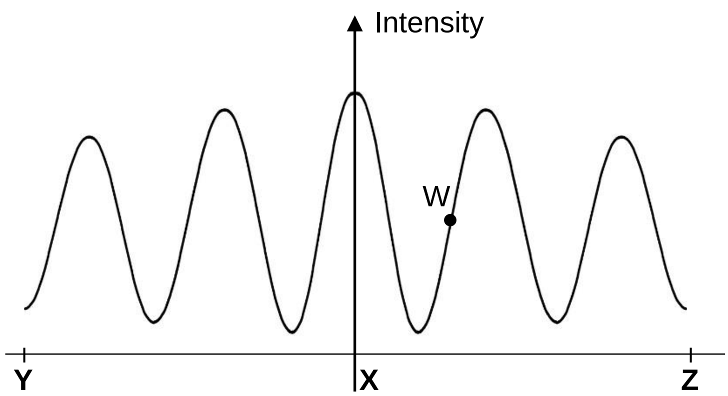


Fig. 4.3

(i) Suggest a reason why the intensity of the minimas are not zero. [2]

(ii) State the phase difference between the waves at point W indicated in Fig. 4.3.

phase difference = …………………rad [1]

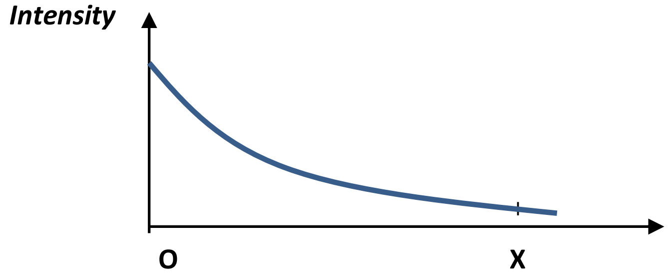
(iii) Describe how the positions and intensities of the maxima and minima may vary when the following changes are made independently.

1. The power of one of the emitters is halved.
……………………………………………………………………………… [3]

2. The microwaves from the two emitters are polarized perpendicularly to each other.
……………………………………………………………………………… [1]

[HCI 2015]

4(a)	The principle of superposition states that **when two or more waves of the same kind overlap**, the **resultant displacement** at any point at any instant is given by the **vector sum of the individual displacements** that each individual wave would cause at that point at that instant.	B1 B1
(b)	The sources must be **coherent**; i.e. they must maintain a *constant phase difference* with respect to each other. The two wave sources must also emit waves of roughly the same amplitude.	B1 B1
(c)(i)	1. P is the waveform with larger amplitude, Q the one with smaller amplitude 2. they are coherent. The phase difference between them is a constant value of π.	B1 B1 A1
(c)(ii)	Path difference, x = QY – PY = $\left(\sqrt{6^2+3^2}-\sqrt{6^2+1^2}\right)d$ x = 0.625 d	B1
(c)(iii)	3rd order minima is formed at Y	

	Path difference = 0.625 d = 2.5 λ λ = 0.25 d f = 3.0x10^8/0.25d = 1.2 x 10^9/d Hz	M1 M1 A1
(c)(iv)	$\frac{\Delta f}{f}=\frac{\Delta\lambda}{\lambda}=\frac{\Delta d}{d}=2\%$	B1
(c)(v)	 Not all positive – minus 1 Approach infinity at O or touch zero at X – minus 1	B2
(d)(i)	The amplitude of the waves caused by P and Q at a point along YZ are different due to significant difference between the distance between that point and the point P and Q. (A is inversely proportional to r) Incomplete destructive interference.	B1 B1
(d)(ii)	1.5 pie	B1
(d)(iii)	1. Positions do not change. Intensity of maxima decreases. Intensity of minima increases. 2.No more maxima and minima.	 B1 B1 B1 B1

5 **(a)** Distinguish between longitudinal and transverse progressive waves. [2]

(b) A loudspeaker is assumed to radiate energy uniformly in all directions at a constant rate and Joshua stands at a distance d from the loudspeaker to listen. After a while, the intensity of the sound is tripled.

(i) Determine, in terms of d, the distance from the loud speaker Joshua should be at if he wishes the sound to seem as loud as before. [2]

distance = ...

(ii) Joshua was initially standing 5.0 m away from the loudspeaker. At this position, the amplitude of vibration of air molecules after the intensity has tripled, is 1.0×10^{-7} m. Determine the amplitude of vibration of air molecules at the new position which Joshua then stands in **(b)(i)**. [2]

amplitude = ... m

(c) A second similar loudspeaker S_2 is connected to the first loudspeaker S_1, such that they are driven in phase from a common audio-frequency source as shown in Fig. 5.1. Joshua is now standing at X, a distance *L* measured from the centre position O of the two loudspeakers.

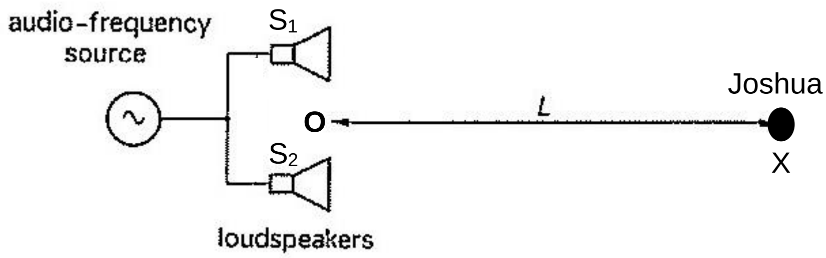
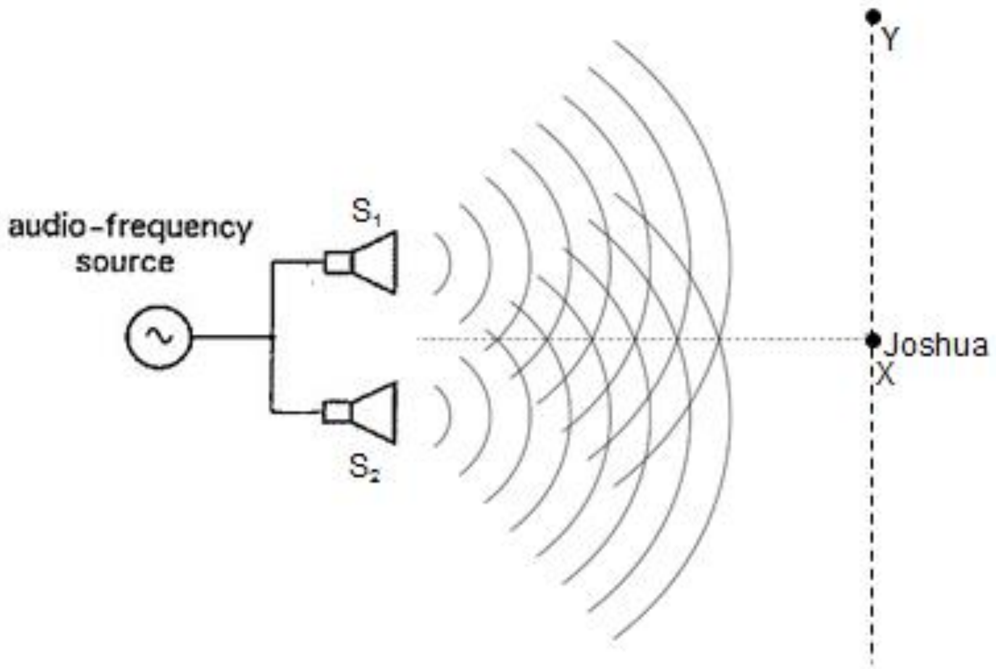


Fig. 5.1

(i) State two conditions that must be satisfied in order that two waves from the loudspeakers may interfere. [2]

(ii) Fig. 5.2 shows the wavefronts emerging from the two loudspeakers.



1. The wavefronts represent successive compressions of the wave. On Fig. 5.2, draw a line to show a direction along which:

- constructive interference may be observed. Label this line **C.**
- destructive interference may be observed. Label this line **D.** [2]

2. Describe what Joshua will hear as he walks from point X towards point Y. [2]

(d) Loudspeaker S_1 is now separated from loudspeaker S_2 and is connected to a signal generator.

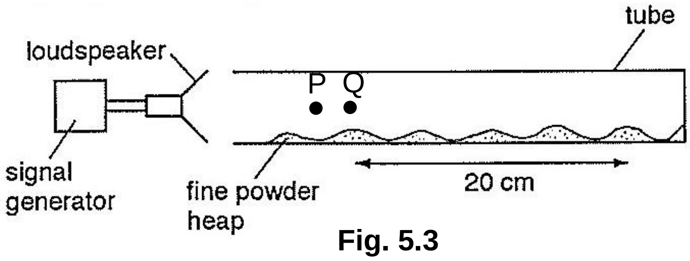


Fig. 5.3

S_1 is positioned at one end of a long horizontal tube which is closed at the other end and contains a fine powder. At a particular frequency, a stationary wave is set up inside the tube and the powder forms heaps as seen in Fig. 5.3. The speed of sound is taken to be 330 m s^{-1}.

(i) Explain how the stationary wave is formed. [2]

(ii) Calculate the frequency of this wave. [2]

frequency = ...Hz

(iii) Two air molecules P and Q are at the respective positions along the pipe as seen in Fig. 5.3.
For the molecules P and Q, state which molecule(s) is at a position of
1. displacement anti-node, [1]
2. loud sound. [1]

(iv) In Fig. 5.4, sketch the variations of displacement s with time t for the two molecules P and Q for one complete cycle of oscillation.
Label the sketches P and Q respectively. [2]

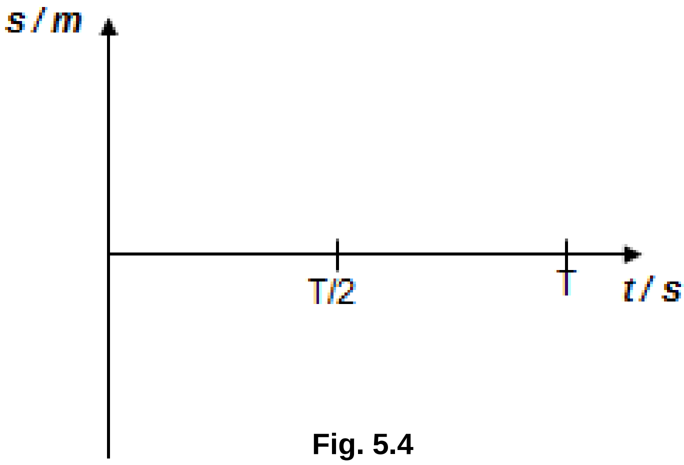


Fig. 5.4

[AJC 2012 P3]

5 (a) For **transverse** waves, the **displacement/disturbance/vibrations/oscillations of medium particles** in the wave are **perpendicular** to **direction of wave travel / transfer of energy**.
For **longitudinal** waves, the **displacement/disturbance/vibrations/oscillations of medium particles** in the wave are **parallel** to **direction of wave travel / transfer of energy**.
OR
The transverse waves can be polarised while the longitudinal waves cannot be polarised as the oscillations of medium particles in a longitudinal wave are parallel to the direction of wave travel while that of the transverse wave is perpendicular to direction of wave travel**.**

(b) (i) Method 1

$$I_1 = \frac{P}{4\pi d_1^{\,2}} \quad \& \quad I_2 = 3I_1 = \frac{3P}{4\pi d_1^{\,2}} \quad \text{ie power has tripled}$$

$$\& \quad I_3 = \frac{(3P)}{4\pi d_3^{\,2}}$$

$$\text{Given } \; I_1 = I_3 \Rightarrow \frac{P}{4\pi d_1^{\,2}} = \frac{(3P)}{4\pi d_3^{\,2}}$$

$$\Rightarrow d_3^{\,2} = 3d_1^{\,2} \Rightarrow d_3 = \sqrt{3}d_1 = \sqrt{3}d = 1.73\,\mathrm{d}$$

OR Method 2

$$\text{For constant P, using } I = \frac{P}{4\pi d^2} \;\Rightarrow I \;\alpha\; \frac{1}{d^2} \;\Rightarrow \frac{I_{new}}{I_{intermediate}} = \frac{d_{intermediate}^{\;\;2}}{d_{new}^{\;\;2}} \Rightarrow \frac{I}{3I} = \frac{d^2}{d_{new}^{\;\;2}}$$

$$\Rightarrow d_{new}^{\;\;2} = \frac{3I}{I}\,d^2 \;\Rightarrow d_{new} = \sqrt{3}\,d = 1.73\,\mathrm{d}$$

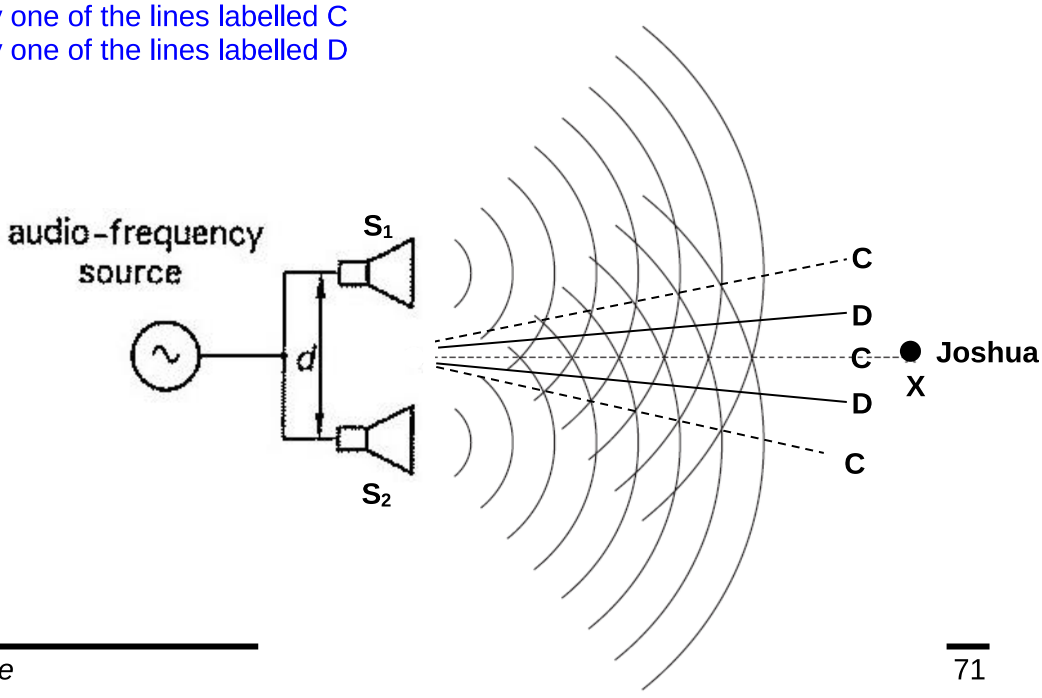
(ii) Since

$$I \;\alpha\; A^2 \Rightarrow \frac{I_{new}}{I_{intermediate}} = \frac{A_{new}^{\;\;2}}{A_{intermediate}^{\;\;2}} \;\Rightarrow \frac{I}{3I} = \frac{A_{new}^{\;\;2}}{A_{intermediate}^{\;\;2}} \;\Rightarrow\; A_{new} = \sqrt{\frac{1}{3}}A_{intermediate}$$

$$\Rightarrow \quad A_{new} = \frac{1}{\sqrt{3}}\left(1.0\times10^{-7}\right) = 5.77\times10^{-8} \approx 5.8\times10^{-8}\,\mathrm{m}$$

(c) (i)
1. The two waves must meet at a point.
2. The two waves must be of the same type of waves.
3. (For mechanical waves in this context) The two waves requires a medium to travel.

(ii) 1. Any one of the lines labelled C
Any one of the lines labelled D



2. Joshua will hear **a series of alternating loud and soft sounds** starting with **a loud sound at point X**.

(d) (i) The progressive longitudinal sound wave is **reflected at the closed end** of the pipe. Hence, there are **two progressive waves** of **equal amplitude and frequency**, travelling with the **same speed in opposite directions** towards each other.
The superposition results in a stationary wave formed.

(ii) From Fig. 7.3, $2\lambda = 20$ cm $\Rightarrow \lambda = 0.10$ m
Using $v = f\lambda \Rightarrow f = v / \lambda = 330 / 0.10 = 3300$ Hz

(iii) 1. position of displacement anti-node – **molecule P**

2. position of loud sound – **molecule Q**
(loud sound $\Rightarrow$ pressure antinode $\Rightarrow$ displacement node)

(iv)
- Position where molecule P is at, is a displacement antinode
  $\Rightarrow$ s-t graph of molecule P would be a **sinusoidal curve**; where displacement of molecule P at t = 0 can be of any value.
- Position where molecule Q is at, is a displacement node
  $\Rightarrow$ s-t graph of molecule Q would be a **horizontal straight line with zero amplitude**.
- Students are to draw for 1 complete cycle and label P & Q clearly as asked in question.

6 (a) Explain what is meant by the *principle of superposition.* [2]

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

(c) An arrangement that can be used to determine the speed of sound in air is shown in Fig. 6.1.

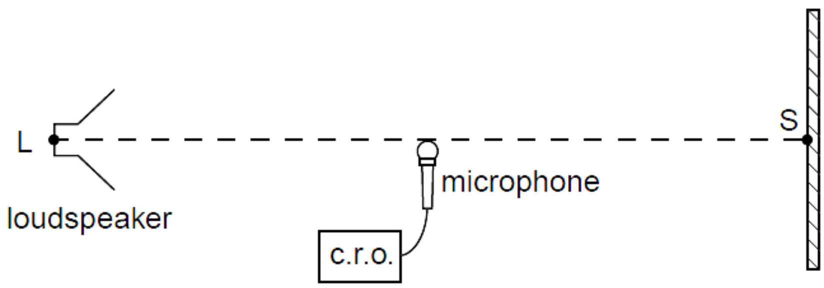


Fig. 6.1

Sound waves of constant frequency are emitted from the loudspeaker L and are reflected from a point S on a hard surface.

The loudspeaker is moved away from S until a stationary wave is produced.

(i) Explain how sound waves from L give rise to a stationary wave between L and S. [2]

(ii) A microphone connected to a cathode ray oscilloscope (c.r.o.) is positioned between L and S as shown in Fig. 6.1. The trace obtained on the c.r.o. is shown in Fig. 6.2.

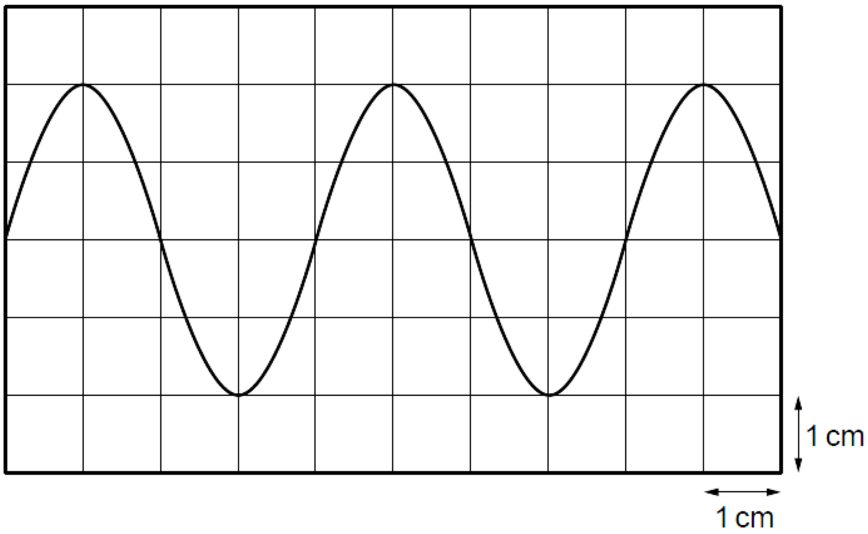


Fig. 6.2

The time-base setting on the c.r.o. is 0.10 ms cm^{-1}.

1. Calculate the frequency of the sound wave. [2]

frequency = ... Hz

2. The microphone is now moved towards S along the line LS. When the microphone is moved 6.7 cm, the trace seen on the c.r.o. varies from a maximum amplitude to a minimum and then back to a maximum. Calculate the speed of sound. [2]

speed of sound = ... m s^{-1}

(d) Describe the diffraction of monochromatic light as it passes through a diffraction grating. [1]

(e) White light is incident on a diffraction grating, as shown in Fig. 6.3.

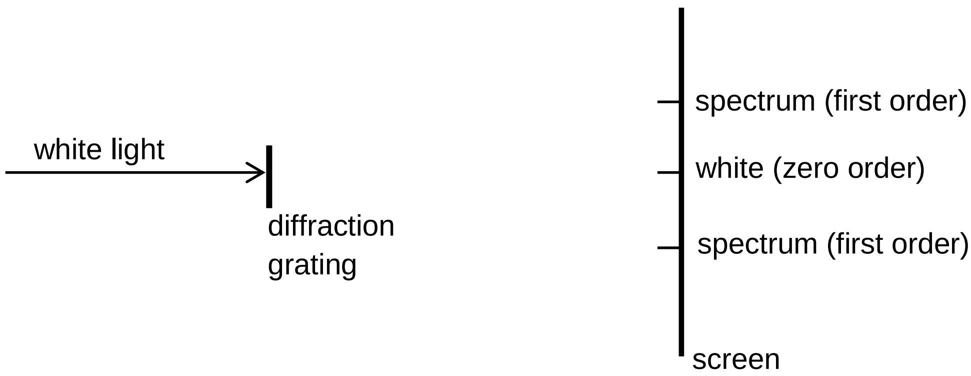


Fig. 6.3

The diffraction pattern formed on the screen has white light, called zero order, and coloured spectra in other orders.

(i) Describe how the principle of superposition is used to explain

1. white light at the zero order, [2]

2. the difference in the position of red and blue light in the first-order spectrum. [2]

(ii) Light of wavelength 625 nm produces a second-order maximum at an angle of 61.0° to the incident direction. Determine the number of lines per metre of the diffraction grating. [2]

Number of lines per metre = ... m^{-1}

(iii) Calculate the wavelength of another part of the visible spectrum that gives a maximum for a different order at the same angle as in **(e)(ii)**. [2]

wavelength = ... nm

[DHS 2013 P3]

6 (a) where two waves of the same kind meet (or overlap) at point, B1
the resultant displacement is the vector sum of displacements due to each wave. B1

(b) to confine the oscillations in one direction,
in a plane perpendicular to the direction of energy transfer. B1
sound wave has oscillation along the direction of energy transfer. B1
so cannot be polarised A0

(c) (i) incident wave and reflected wave overlap B1
the two waves have same speed and frequency (or wavelength) B1

(ii) 1. period = 0.10 x 4 = 0.40 ms C1

frequency = $\frac{1}{0.40\times10^{-3}}$ = 2500 Hz A1

2. $\frac{1}{2}\lambda = 6.7$ cm M1

λ = 13.4 cm

$v = f\lambda$ C1

= 2500 x 0.134 = 335 m s^{-1} A1

Comments: For (c)(i), many candidates assume the incident wave and reflected wave will overlap or meet. This must be stated as one of the pre-requisite conditions to formation of stationary wave.

(d) Light waves passing through slits spread into geometric shadow A1

(e) (i) 1. at zeroth order, each wavelength travels the same distance,
i.e. path difference is zero. B1
all wavelengths meet there and superpose in phase. B1
hence produce a maximum
mixture of all wavelengths form white light A0

2. for 1st order maxima, the path difference must be 1 λ B1
blue and red light have different wavelengths B1
hence maxima formed at different locations A0

(ii) $d\,sin\theta = n\lambda$ C1

$\frac{1}{d} = \frac{sin61.0}{2\times625\times10^{-9}} = 7.00\times10^{5}$ A1

(iii) $n\lambda = 2\times625\times10^{-9}$ is a constant C1

$1\times\lambda = 1250$ nm (out of visible light)

$3\times\lambda = 2\times625\times10^{-9}$

So, $\lambda = 417$ nm (within visible light) A1

Comments: This question is well attempted by many students.

7 **(a)** **(i)** A student is conducting some wave experiments on a water tank in the physics laboratory. He sets up a water tank with two *coherent* oscillators, D_1 and D_2 that create circular ripples in the water. The waves generated have the same frequency and wavelength.

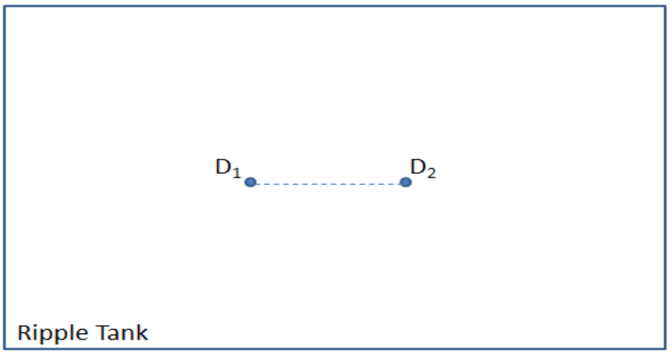


Fig 7.1

Explain what is meant by the term *coherent.* [1]

(ii) The student states that coherent sources are needed for an interference pattern to be observed. Describe what will be observed if incoherent sources are used and explain whether you agree with the student's statement. [2]

(iii) A student states that the intensity of the water wave is inversely proportional to the **square of the distance from the source** and hence, this **energy loss** will cause the ripple amplitude to decrease. Comment critically on the students' statement. [2]

(iv) State the conditions required for stationary waves to be formed and explain whether a stationary wave will be formed along the line D_1D_2 in Fig 7.1. [2]

(v) In Fig 7.2, sketch in the first two modes of vibration that might possibly be observed along the dotted line joining D_1 and D_2. It is assumed that the amplitude of the oscillators, D_1 and D_2, is negligible compared to the amplitude of the water waves. [2]

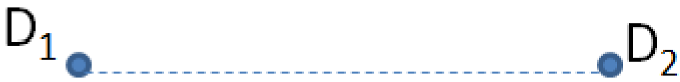


Fig 7.2

(vi) Fig 7.3 shows the wavefronts of the two waves. The dotted lines are wavefronts representing the **equilibrium** position of the waves; the continuous lines are wavefronts representing the **crest** of the waves.

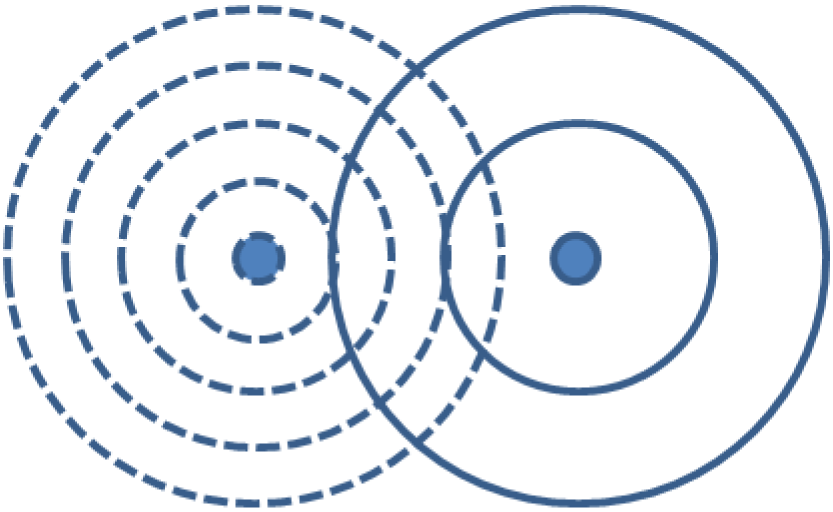


Fig 7.3

1. Using Fig. 7.3., deduce the phase difference between the two sources. [1]

2. On Fig. 7.3, indicate a point where complete destructive interference will possibly take place. Label this point as **X** and briefly explain how you have identified this point. [2]

[NJC 2012 P3]

7(a) (i) Constant phase difference between waves generated by the oscillators

(ii)
If incoherent sources are used, the interference will be changing with time, which means that no consistent pattern can be seen. Only with coherent sources can we observe an interference that does not change with time, so yes, I agree with the student.

(iii) Student's statement is incorrect:

Firstly, $I \propto \frac{1}{r}$ and not the square of the amplitude as this is a 2D wave and not a 3D wave.

Secondly, it is the energy spreading out over a larger area (not energy loss) that causes the amplitude to drop. The amplitude will drop even if there is no energy loss to the surroundings.

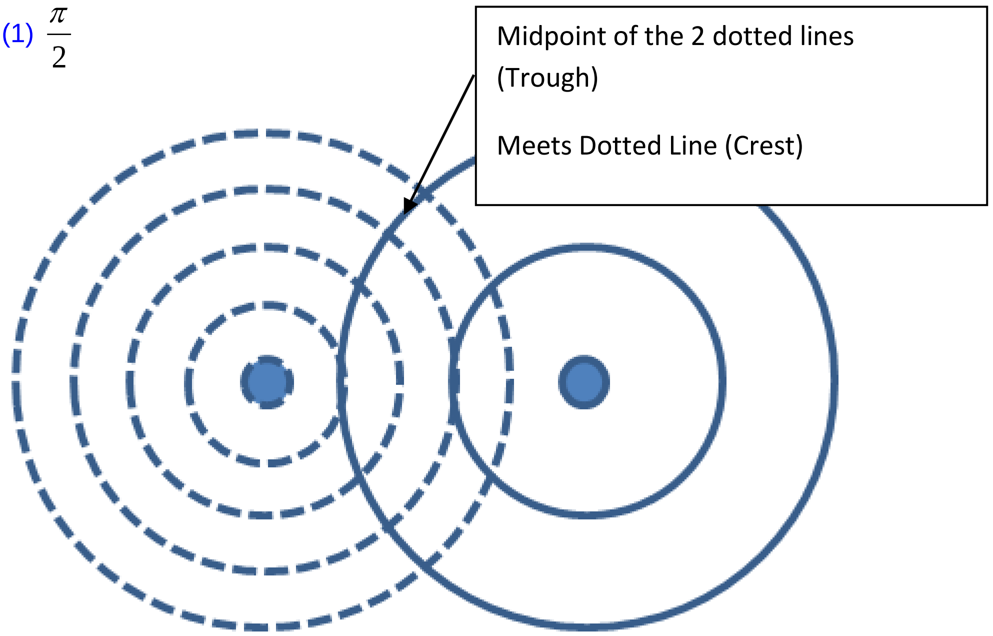
(iv) Same speed, opposite directions, same frequency, amplitude
Yes. Stationary wave will be formed as the above mentioned conditions are met

(v)

Assume initial phase difference of oscillators (eg for first mode, if they are assumed to be in phase, then midpoint between oscillators should be constructive interference. So there should be nodes at the end)
Amplitude of second mode must be less than first mode

(v)(i) (1) $\frac{\pi}{2}$

(2)



8 The first microwave oven was invented by Percy Spencer after World War II, based on the fundamentals of radar technology developed during the war. Microwave ovens heat foods that have high water content, quickly. If the presence of water is negligible in the microwaved item, the item rarely gets hot. The operating frequencies of microwave ovens are usually within the range of 915 MHz and 2.45 GHz, respectively.

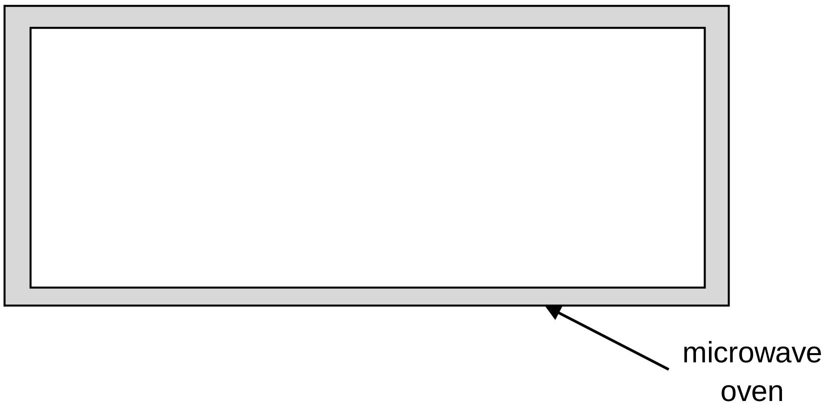
(a) State three conditions for the formation of stationary waves. [3]

(b) During operation, stationary waves are formed within the chamber. Given that, for a particular brand of microwave oven, the frequency generated is 2.00 GHz and the cooking chamber is 45 cm wide.

(i) Determine the number of antinodes under the given conditions, assuming displacement nodes are found at both ends of the cooking chamber. [2]

number of antinodes = ...

(ii) Sketch the stationary waves in the given diagram below. Label the positions of displacement nodes and antinodes. [2]



(ii) In order to investigate the wavelength of microwaves, using laboratory equipment and apparatus, suggest an experimental procedure to determine the wavelength, assuming you do not know the frequency of the electromagnetic waves. Include relevant diagram of the setup [3]

(c) **(i)** When food placed on a porcelain plate is heated in the microwave oven, the food becomes very hot, while the plate remains relatively cooler. Discuss how a microwave oven cooks the food that is placed in the cooking chamber. [2]

(ii) Suggest and explain the highest temperature the food could reach by this cooking method of microwaving. [2]

(d) A microwave source emits progressive transverse waves which pass through a diffraction grating.

(i) Explain what is meant by a *progressive transverse* wave. [3]

(ii) A certain order of diffraction for 2.00 GHz is superimposed on 2.45 GHz microwaves of the next order, where the angle of diffraction is 67°. These diffractions are also the largest order of diffraction for the respective frequencies.

Determine the number of lines per metre in the grating. Leave your answer to 2 significant figures. [3]

number of lines per metre = ... m^{-1}

[RVHS 2013 P3]

8 (a) two progressive waves of equal amplitude B1
equal frequency and speed B1
travelling from opposite directions and meet B1

(b) **(i)** $v = f\lambda$

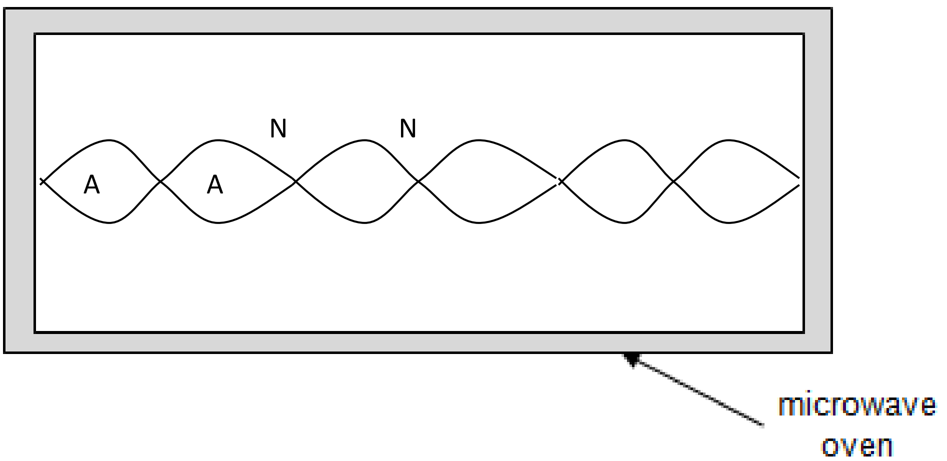
$3 \times 10^8 = (2 \times 10^9)\,\lambda \rightarrow \lambda = 0.15$ m

M1

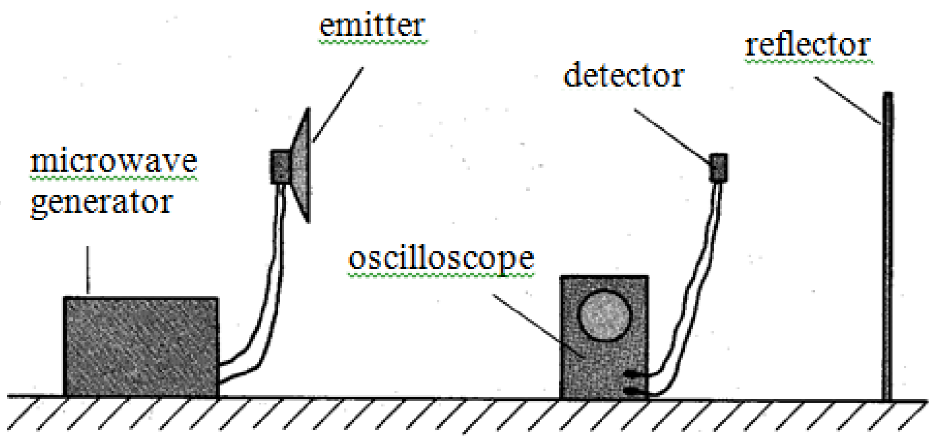
when standing waves generated, distance between two adjacent nodes/antinodes equal to half a wavelength.

6 antinodes A1

(ii)



(iii)



relevant diagram given B1

Microwave generator produces mcirowave through an emitter. These waves are reflected back by the reflector and the two waves superpose to give a stationary wave. B1

A microwave detector is placed between the emitter and the reflector to detect the nodes and antinodes of the stationary wave. Detector is connected to a cathode-ray oscilloscope (CRO) with the time-base turned off.

By moving the microphone slowly backward and forward, a vertical trace can be seen on the screen of the CRO which varies from a minimum length to a maximum length corresponding to the nodes and antinodes.

Measuring the length between successive nodes or antinodes of the stationary wave will give $\lambda/2$. From this measurement, the wavelength λ of the sound waves can be obtained. B1

(c) **(i)** food contains high water content.
energy of microwave transfers to water molecules in food B1
water molecules vibrate more energetically as a result of energy transfer from the microwave, transferring energy to the rest of the food as thermal energy B1

(ii) food contains water and boiling point of water is 100°C B1
so highest temperature reached would be 100°C B1

(d) **(i)** A *progressive transverse wave*is a wave in which the energy transfer is in the direction of wave motion while displacements of the particles in the wave are at right angles to the direction of transfer of the energy of the wave. B1 B1 B1

(ii) $d\sin\theta=n\lambda$

2.00 GHz → 0.15 m wavelength
2.45 GHz → 0.122 m wavelength

$d\sin\theta=(n)(0.15)$ M1
$d\sin\theta=(n+1)(0.122)$

$0.15n = 0.122n + 0.122$

n = 4.35 M1

largest order of diffraction, assume → d(sin90) = 4.35(0.15)

average number of lines per metre = 1/d = 1.53 A1