PROSPERITY ACADEMY

AS PHYSCIS 9702

Crash Course

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SUPERPOSITION

COMPLETE NOTES

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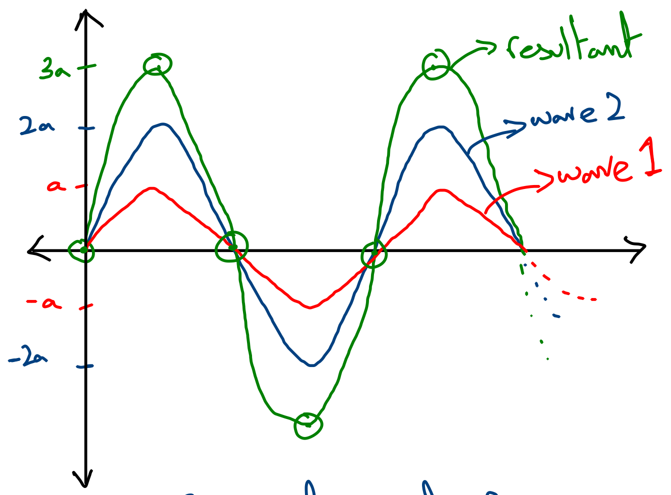
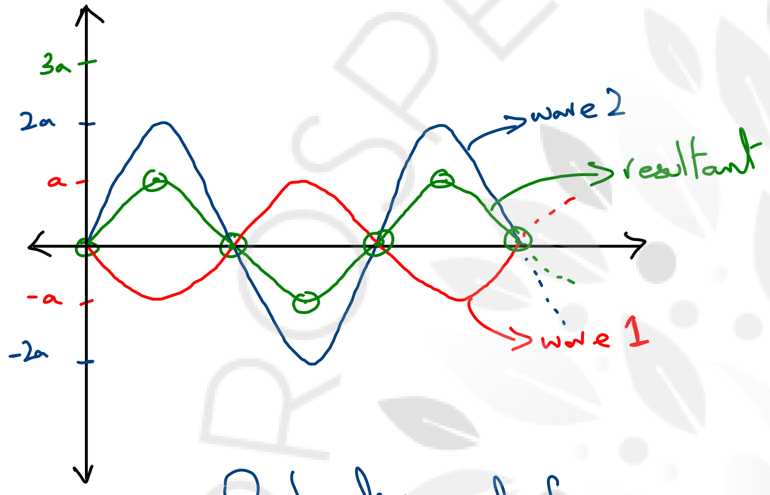
Superposition:-

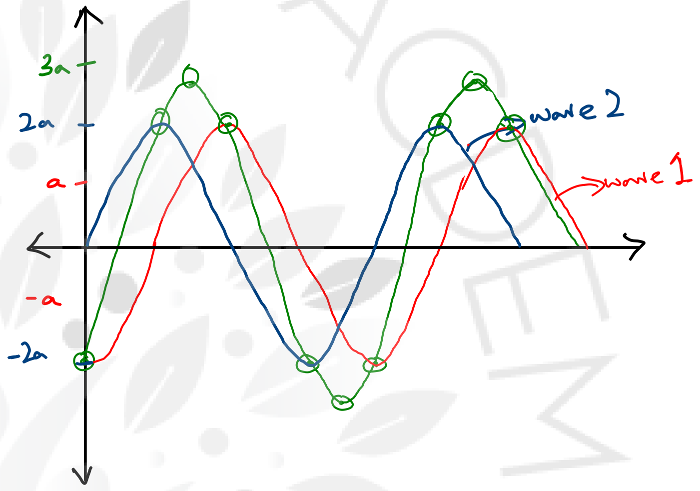
Principle of superposition:- When 2 or more waves of the same nature meet at a point, the resultant displacement is the algebraic sum of the individual displacements at that point.



Constructive interference



Destructive interference

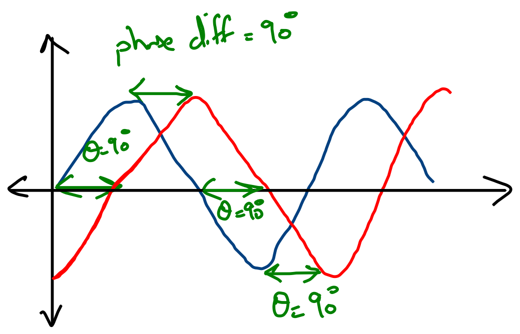


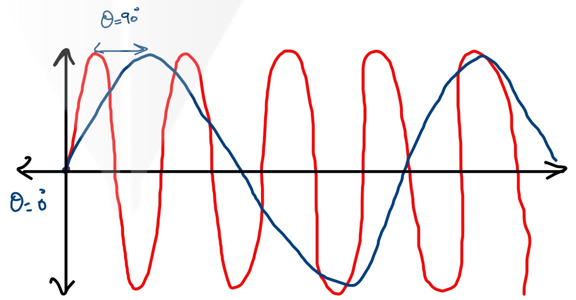
Interference:-

Whenever 2 waves superpose, they shall produce an interference pattern if:-

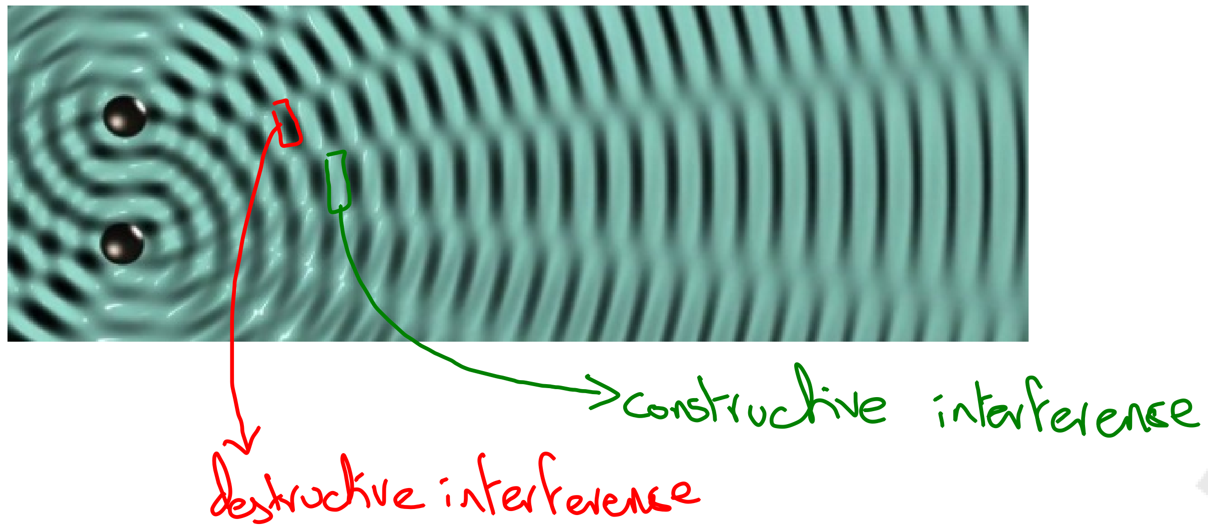
1) same nature and frequency
2) they should meet at a point
3) They should have the same polarization
4) They should have a constant phase relationship (They must be coherent)

Same T, same λ



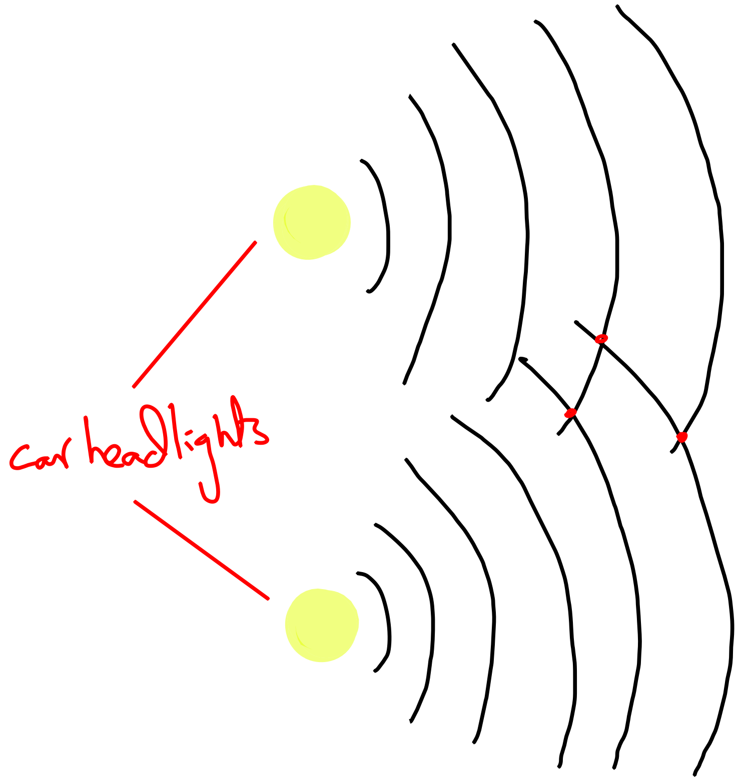


θ can be anything but it must be constant



Interference pattern:- A beautiful pattern of alternating maximum and minimum displacement

Q. Why do car head lights not produce an interference pattern?



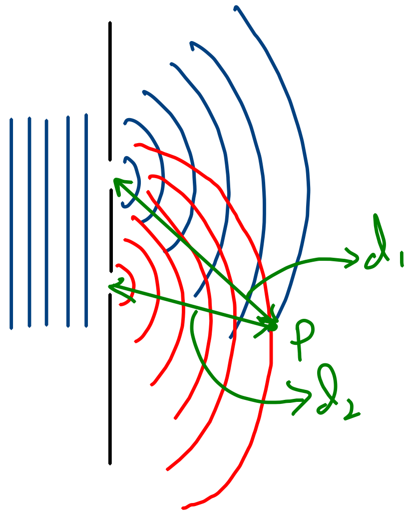
1) They are not coherent

2) They dont have same frequency

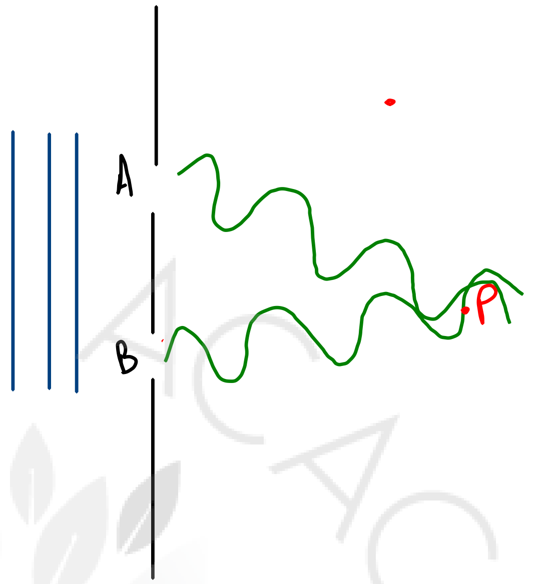
3) They may not be polarised similarly

4) $\downarrow x = \frac{\lambda D}{a \uparrow}$

How to produce a light interference pattern?



coherent ✓
same frequency ✓
same polarisation ✓



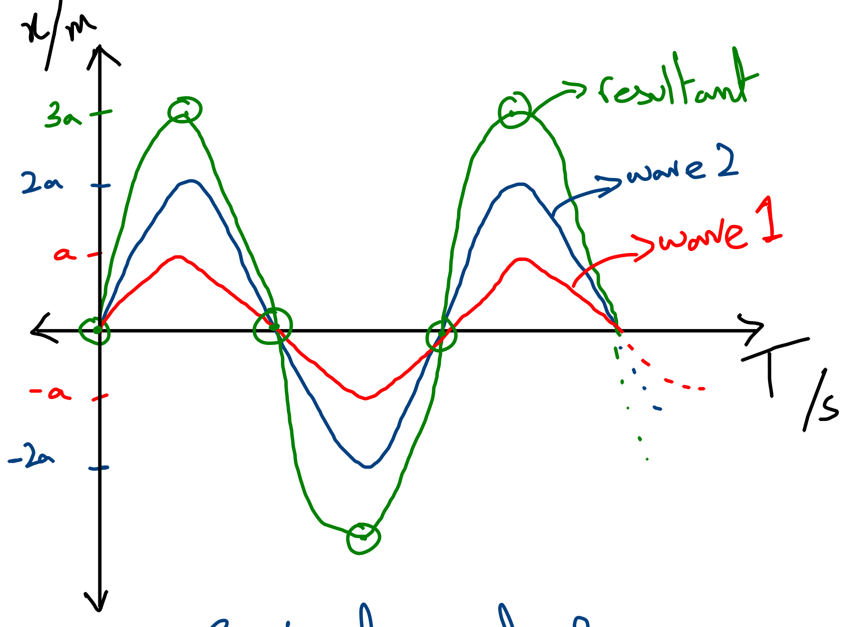
constant phase diff = 0°

✳ we will split a single source into 2

Path difference at P = $d_1 - d_2$

Path difference:- The difference in distances travelled by 2 coherent waves interfering at a point.

Constructive interference:- When 2 waves, 0° out of phase superpose at a point, the resultant displacements are always greater than the individual displacements



Constructive interference

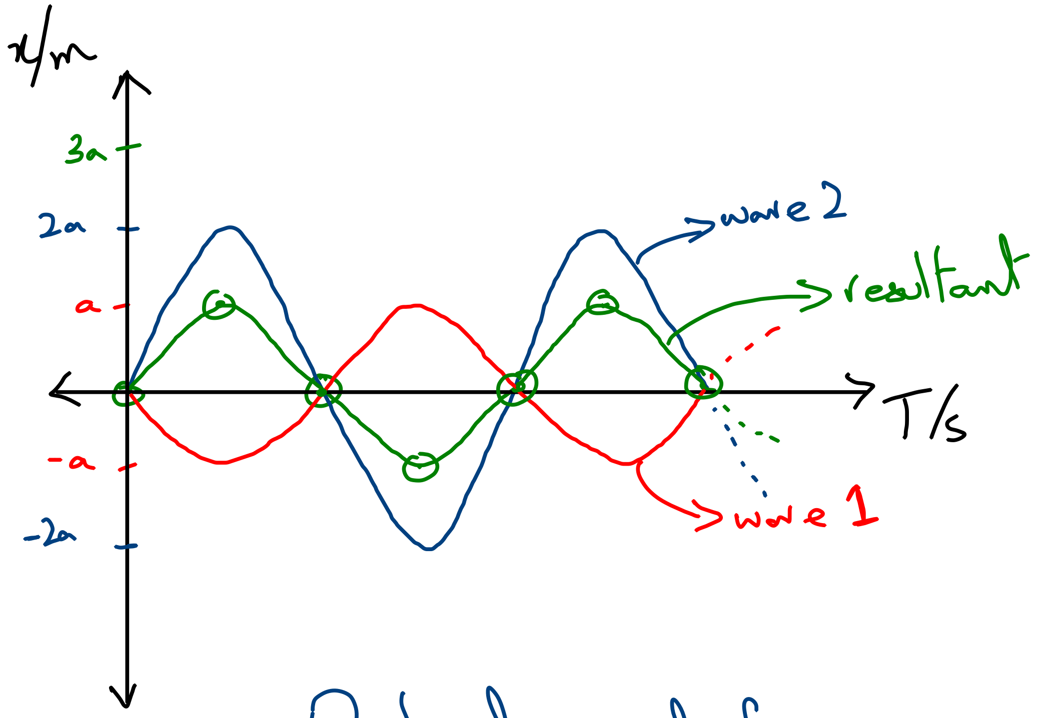
If the waves at the point of origination were 0° out of phase (constant phase difference = 0°)

then if a point has a path difference of $\boxed{P.D. = n\lambda}$, then the 2 waves constructively interfere.

n can only be a whole number i.e. 1, 2, 3, 4 and so on...

Phase difference = $\frac{\Delta x}{\lambda} \times 360° = \frac{n\cancel{\lambda}}{\cancel{\lambda}} \times 360° = 360° n$

Destructive interference:- When 2 waves, 180° out of phase superpose at a point, the resultant displacements are never greater than the individual displacements



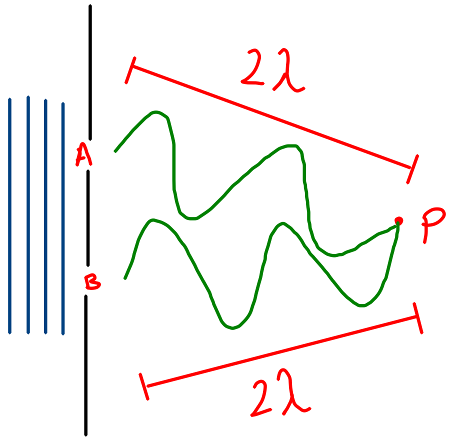
Destructive interference

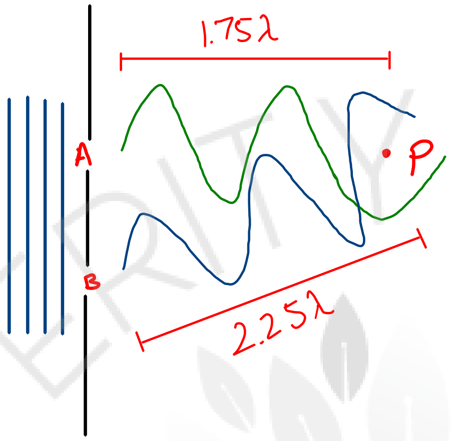
Destructive interference

If the waves at the point of origination were 0° out of phase (constant phase difference = 0°) then if a point has a path difference of $\boxed{P.D = \left(n+\frac{1}{2}\right)\lambda}$, then the 2 waves destructively interfere.

for eg P.D = 2.5λ, 0.5λ, 6.5λ

Phase difference = $\frac{\Delta x}{\lambda} \times 360° = \frac{\left(n+\frac{1}{2}\right)\cancel{\lambda}}{\cancel{\lambda}} \times 360° = 360°n + 180°$





$P.D = 2\lambda - 2\lambda = 0\lambda$

$\therefore$ Constructive interference as $P.D = n\lambda$

$P.D. = 2.25\lambda - 1.75\lambda = 0.5\lambda$

$\therefore$ Destructive interference as $P.D = (n+\frac{1}{2})\lambda$

Proving a point for constructive/destructive interference:-

Constructive $\Rightarrow n\lambda = P.D$

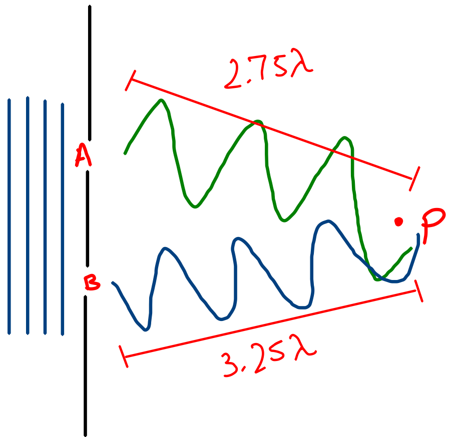
Destructive $\Rightarrow (n+\frac{1}{2})\lambda = P.D$

Proof $\Rightarrow \dfrac{P.D}{\lambda} = n \;/\; n+\frac{1}{2}$

Note:- If the phase difference between the waves at the point of origination is 180° (constant phase difference $= 180^\circ$), then

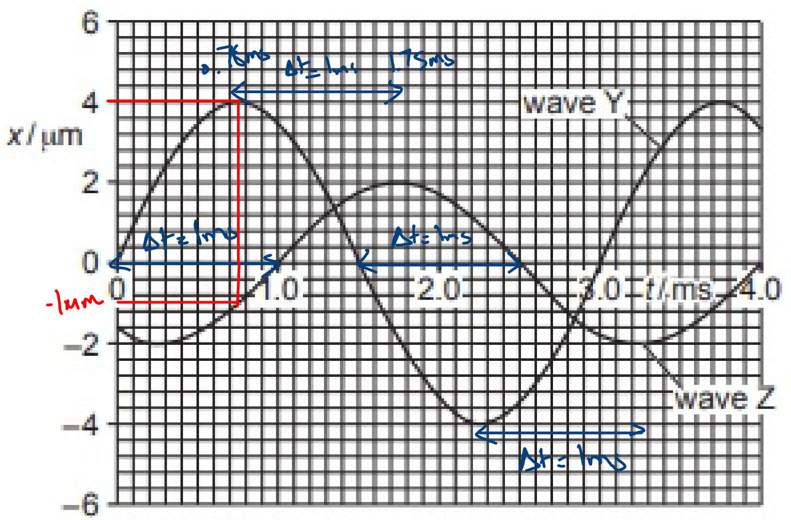
Constructive:- $P.D = (n+\frac{1}{2})\lambda$

Destructive:- $P.D = n\lambda$



$P.D = 3.25\lambda - 2.75\lambda = 0.5\lambda$

4 Two progressive sound waves Y and Z meet at a fixed point P. The variation with time t of the displacement x of each wave at point P is shown in Fig. 4.1.



$T = 3ms$

$T = 3ms$

Fig. 4.1

(a) Use Fig. 4.1 to state **one** quantity of waves Y and Z that is:

(i) the same

Time period / frequency ..... [1]

(ii) different.

Amplitude ..... [1]

(b) State and explain whether waves Y and Z are coherent.

They are coherent as they have a constant phase difference ..... [1]

(c) Determine the phase difference between the waves.

$$\frac{\Delta t}{T} \times 360^\circ = \frac{1 \cancel{\times 10^{-3}}}{3 \cancel{\times 10^{-3}}} \times 360 = 120^\circ$$

phase difference = 120° ..... ° [1]

(d) The two waves superpose at P. Use Fig. 4.1 to determine the resultant displacement at time $t = 0.75$ ms.

$$4 + (-1) = 3\ \mu m$$

(e) The intensity of wave Y at point P is I.

Determine, in terms of I, the intensity of wave Z.

$$\frac{I_1}{a_1^2} = \frac{I_2}{a_2^2}$$

$$\frac{I}{(4\times10^{-6})^2} = \frac{I_3}{(2\times10^{-6})^2} \Rightarrow I_3 = \frac{(2\times10^{-6})^2\, I}{(4\times10^{-6})^2} = 0.25 I$$

intensity = $0.25 I$ ..... [2]

(f) The speed of wave Z is $330\,m\,s^{-1}$.

Determine the wavelength of wave Z.

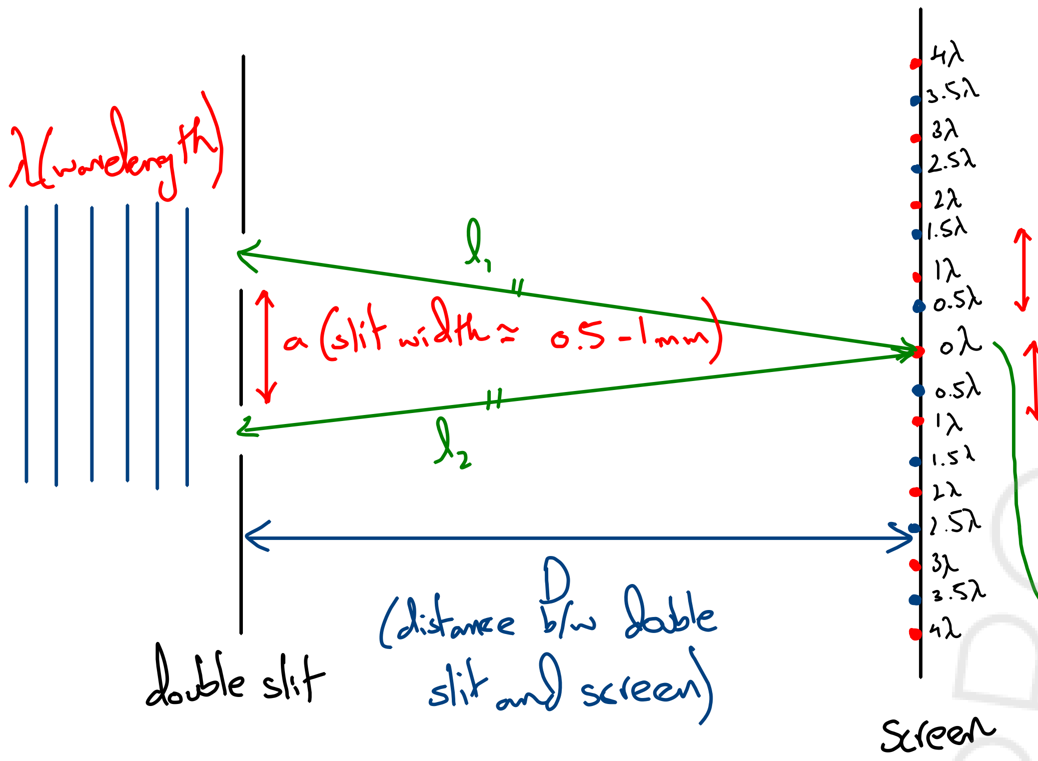
$$f = \frac{1}{3\times10^{-3}}$$

$$v = f\lambda$$

$$330 = \frac{1}{3\times10^{-3}} \times \lambda$$

$$\lambda = 0.99\,m$$

Young's Double slit experiment :-



x (fringe width)

x (fringe width)

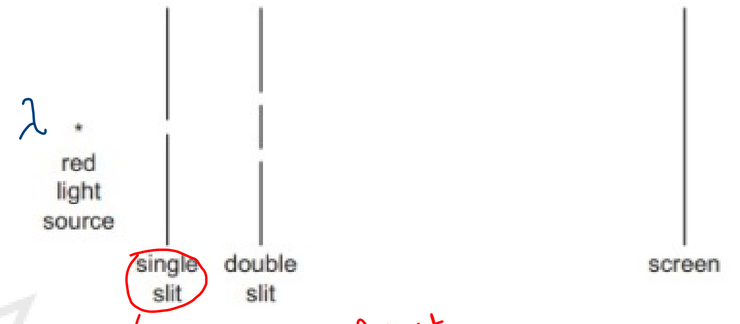
(distance between 2 successive bright spots/dark spots)

$P.D = l_1 - l_2 = 0\lambda$

- bright spots : constructive interference
- dark spots : destructive interference

$$\boxed{x = \frac{\lambda D}{a}}$$

28 A double-slit interference experiment is set up as shown.



↳ to make sure red light is incident on both slits

Fringes are formed on the screen. The distance between successive bright fringes is found to be 4 mm. = x

Two changes are then made to the experimental arrangement. The double slit is replaced by another double slit which has half the spacing. The screen is moved so that its distance from the double slit is twice as great.

What is now the distance between successive bright fringes? $\boxed{16\,mm}$

Expt 1

$\lambda,\ x = 4mm,\ D,\ a$

$x = \frac{\lambda D}{a}$

$4\times10^{-3} = \frac{\lambda D}{a}$

Expt 2 :-

$\lambda,\ x = ?,\ 2D,\ \frac{1}{2}a$

$x_2 = \frac{\lambda \times 2D}{\frac{1}{2}a}$

$x_2 = 4\frac{\lambda D}{a} \rightarrow x$

$x_2 = 4\times 4\times10^{-3} = 16\times10^{-3}$

16mm

4 **(a)** State three conditions that must be satisfied in order that two waves may interfere.

1. They must be coherent

2. Same frequency and nature

3. They must have same polarisation [3]

(b) The apparatus illustrated in Fig. 4.1 is used to demonstrate two-source interference using light.

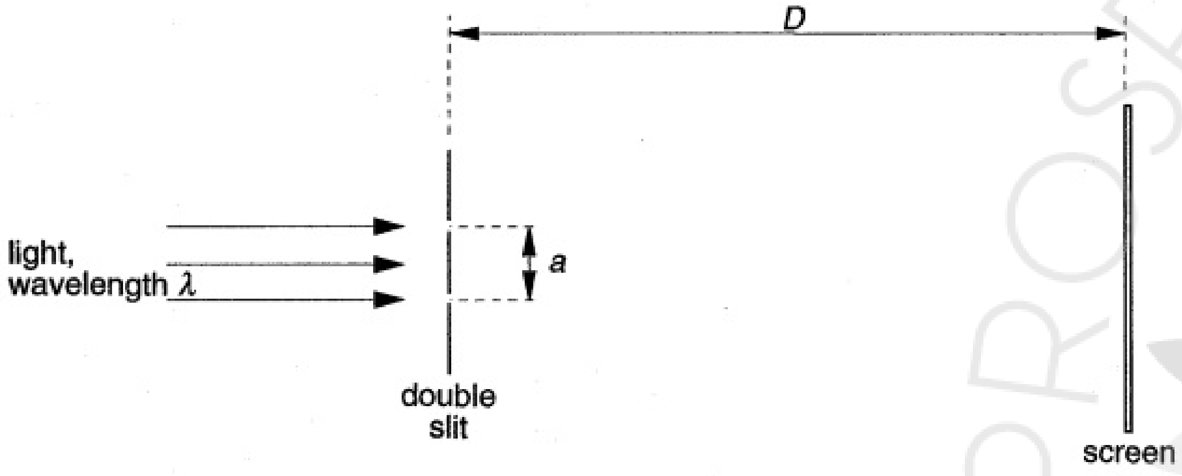


Fig. 4.1 (not to scale)

The separation of the two slits in the double slit arrangement is *a* and the interference fringes are viewed on a screen at a distance *D* from the double slit. When light of wavelength λ is incident on the double slit, the separation of the bright fringes on the screen is *x*.

(i) **1.** Suggest a suitable value for the separation *a* of the slits in the double slit.

0.5mm – 1mm (Write one value)

2. Write down an expression relating λ, *a*, *D* and *x*.

$x = \lambda D / a$

[2]

(ii) Describe the effect, if any, on the separation and on the maximum brightness of the fringes when the following changes are made.

1. The distance *D* is increased to 2*D*, keeping *a* and λ constant.

separation: doubles, as $x \propto D$

maximum brightness: decreases as intensity decreases by a factor of 4

2. The wavelength λ is increased to 1.5λ, keeping *a* and *D* constant.

separation: increases by a multiple of 1.5

maximum brightness: less bright as $I \propto f^2$

3. The intensity of the light incident on the double slit is increased, keeping λ, *a* and *D* constant.

separation: Same

maximum brightness: increases as incident intensity increased

[7]

1) $x = \frac{\lambda D}{a}$ const $\Rightarrow 2x \propto 2D$

$I \propto \frac{1}{r^2} \Rightarrow I_1 r_1^2 = I_2 r_2^2$

$I_1 \cancel{D^2} = I_2 \, 4\cancel{D^2}$

$\frac{I_1}{4} = I_2$

2) $x = \frac{\lambda D}{a}$ const $\Rightarrow 1.5x \propto 1.5\lambda$

3) $x = \frac{\lambda D}{a}$

const

$v = \downarrow f \, \lambda \uparrow$

$\downarrow I \propto f^2 \downarrow$

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

$I \propto \frac{1}{\lambda^2}$

$\lambda \propto \frac{1}{f}$

$f \propto \frac{1}{\lambda}$

$I_1 \lambda_1^2 = I_2 \lambda_2^2$

$I_1 \cancel{\lambda_1^2} = I_2 \, 2.25 \cancel{\lambda^2}$

$I_2 = \frac{I_1}{2.25}$

6 **(a)** Interference fringes may be observed using a light-emitting laser to illuminate a double slit. The double slit acts as two sources of light.

Explain

(i) the part played by diffraction in the production of the fringes,

As the light passes through the slit, it spreads into its geometric shadow so that the 2 waves superpose at many spots and create an interference pattern. [2]

(ii) the reason why a double slit is used rather than two separate sources of light.

So that the 2 waves have a constant phase relationship [1]

(b) A laser emitting light of a single wavelength is used to illuminate slits S_1 and S_2, as shown in Fig. 6.1.

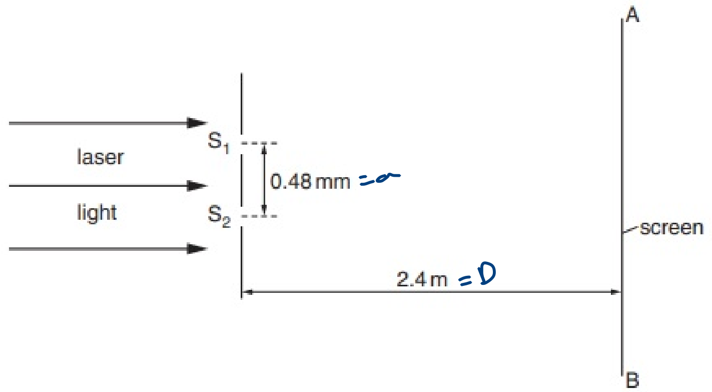


Fig. 6.1 (not to scale)

An interference pattern is observed on the screen AB. The separation of the slits is 0.48 mm. The slits are 2.4 m from AB. The distance on the screen across 16 fringes is 36 mm, as illustrated in Fig. 6.2.

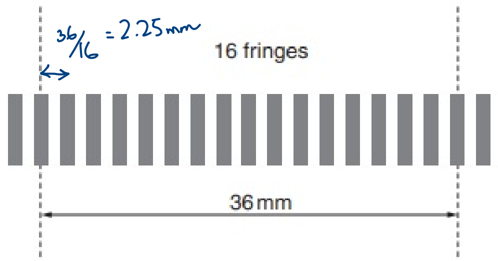


Fig. 6.2

Calculate the wavelength of the light emitted by the laser.

$$x = \frac{\lambda D}{a} \Rightarrow (2.25 \times 10^{-3}) = \frac{\lambda (2.4)}{(0.48 \times 10^{-3})}$$

$$\lambda = 4.5 \times 10^{-7} \simeq 450 \times 10^{-9} \simeq 450 \text{ nm}$$

blue light

Q. To which group of the EM spectrum does this belong?

(c) Two dippers D_1 and D_2 are used to produce identical waves on the surface of water, as illustrated in Fig. 6.3.

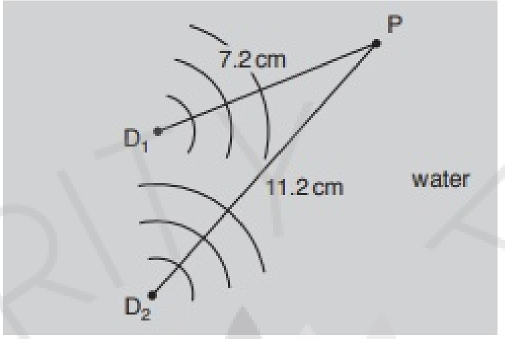


Fig. 6.3 (not to scale)

$$P.D = \frac{11.2 - 7.2}{1.6} = 2.5$$

destructive

Point P is 7.2 cm from D_1 and 11.2 cm from D_2.

The wavelength of the waves is 1.6 cm. The phase difference between the waves produced at D_1 and D_2 is zero.

At : phase difference

$n\lambda$ = constructive

$(n + \frac{1}{2})\lambda$ = Destructive

(i) State and explain what is observed at P.

The water at P will be flat (no vibration) as the path difference of P is 2.5λ so there is destructive interference. [2]

(ii) State and explain the effect on the answer to **(c)(i)** if the apparatus is changed so that, separately,

1. the phase difference between the waves at D_1 and at D_2 is 180°,

There will be vibration at P as waves will now constructively interfere.

2. the intensity of the wave from D_1 is less than the intensity of that from D_2.

There will be vibrations at P as the amplitudes of the waves from D_2 and D_1 will not be same and therefore complete cancellation won't take place. [2]

5 Microwaves with the same wavelength and amplitude are emitted in phase from two sources X and Y, as shown in Fig. 5.1.

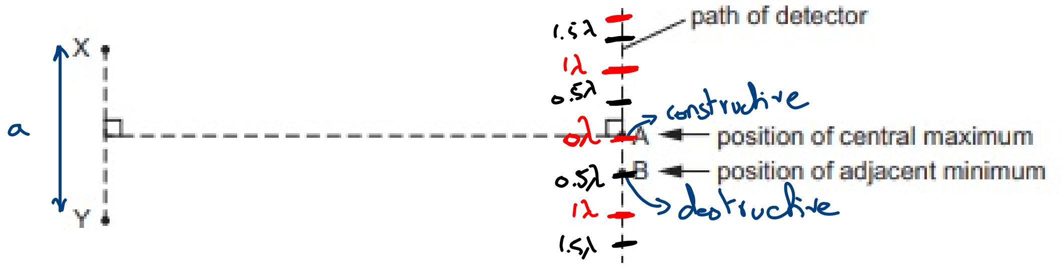


Fig. 5.1 (not to scale)

A microwave detector is moved along a path parallel to the line joining X and Y. An interference pattern is detected. A central intensity maximum is located at point A and there is an adjacent intensity minimum at point B. The microwaves have a wavelength of 0.040 m.

(a) Calculate the frequency, in GHz, of the microwaves.

$v = f\lambda$

$(3\times10^8) = (f)(0.040)$

$f = 7.5\times10^9$

frequency = 7.5 GHz [3]

(b) For the waves arriving at point B, determine:

(i) the path difference

0.5×0.040

path difference = 0.020 m [1]

(ii) the phase difference.

phase difference = 180 ° [1]

(c) The amplitudes of the waves from the sources are changed. This causes a change in the amplitude of the waves arriving at point A. At this point, the amplitude of the wave arriving from source X is doubled and the amplitude of the wave arriving from source Y is also doubled.

Describe the effect, if any, on the intensity of the central maximum at point A.

The intensity increased by a factor of 4.

[2]

(d) Describe the effect, if any, on the positions of the central intensity maximum and the adjacent intensity minimum due to the following separate changes.

(i) The separation of the sources X and Y is increased.

$\downarrow x = \frac{\lambda D}{a\uparrow}$

They will move closer together

[1]

(ii) The phase difference between the microwaves emitted by the sources X and Y changes to 180°.

The positions of maximums and minimums will flip

[1]

[Total: 9]

① $\overset{a}{X} \;\&\; \overset{a}{Y} \rightarrow A$

$I\,,\ 2a$

② $\overset{2a}{X} \;\&\; \overset{2a}{Y} \rightarrow A$

$I_2\,,\ 4a$

$\frac{I_1}{a_1^2} = \frac{I_2}{a_2^2}$

$\frac{I}{(2a)^2} = \frac{I_2}{(4a)^2} \Rightarrow \frac{I}{\cancel{4a^2}} = \frac{I_2}{4\,\cancel{16a^2}}$

$I_2 = 4I$

5 **(a)** By reference to two waves, state:

(i) the principle of superposition

When 2 waves of the same nature meet at a point, the resultant amplitude is the algebraic sum of the individual amplitudes.

....[2]

(ii) what is meant by *coherence*.

The 2 waves have a 0° phase difference.

....[1]

(b) Two coherent waves P and Q meet at a point in phase and superpose. Wave P has an amplitude of 1.5 cm and intensity I. The resultant intensity at the point where the waves meet is $3I$.

0° → constructive

resultant amplitude ⇒ 1.5 cm + a_Q

Calculate the amplitude of wave Q.

$$\frac{I_1}{a_1^2} = \frac{I_2}{a_2^2}$$

$$\frac{\cancel{I}}{1.5} = \frac{3\cancel{I}}{1.5 + a_Q} \Rightarrow 1.5 + a_Q = 4.5$$

$$a_Q = 3 \text{ cm}$$

amplitude = 3.0 cm [2]

(c) The apparatus shown in Fig. 5.1 is used to produce an interference pattern on a screen.

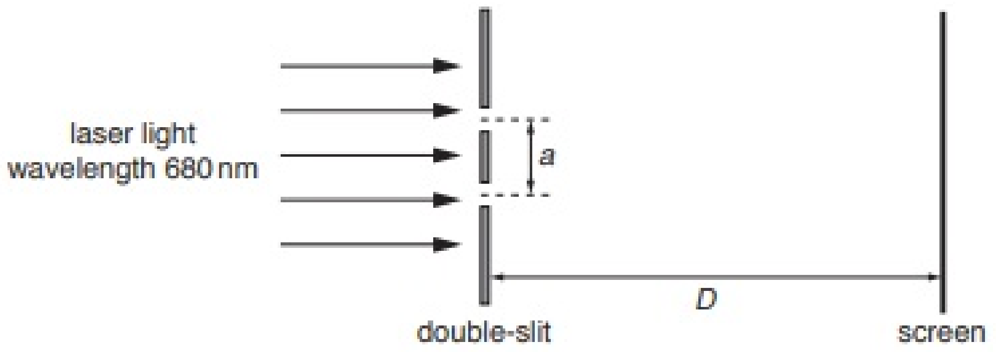


Fig. 5.1 (not to scale)

Light of wavelength 680 nm is incident on a double-slit. The slit separation is a. The separation between adjacent fringes is x. Fringes are viewed on a screen at distance D from the double-slit.

Distance D is varied from 2.0 m to 3.5 m. The variation with D of x is shown in Fig. 5.2.

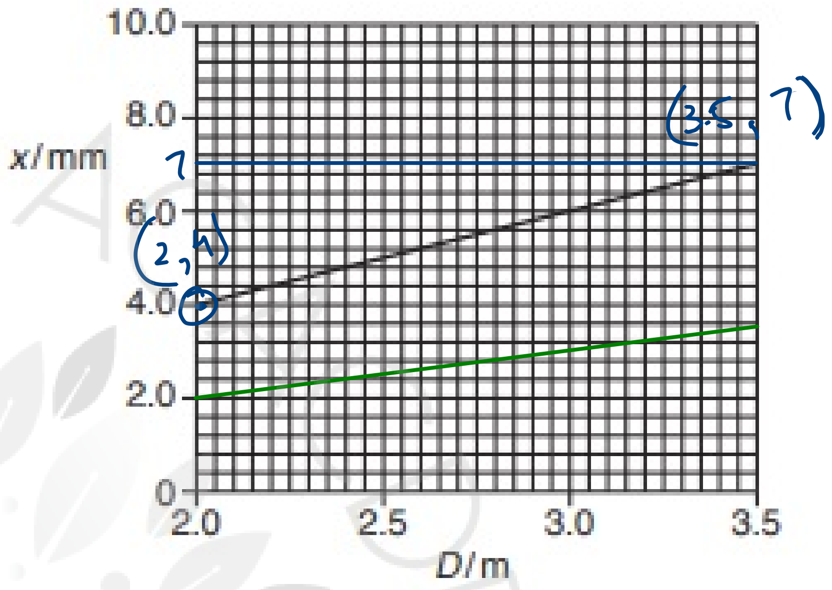


Fig. 5.2

Linear law:-

$$x = \left(\frac{\lambda}{a}\right) \times D + 0$$

$$y = (m)\, x + 0$$

$$\downarrow x = \frac{\downarrow\lambda}{a} \times D$$

$$\downarrow m = \frac{\downarrow\lambda}{a}$$

(i) Use Fig. 5.2 to determine the slit separation a.

$$m = \frac{\lambda}{a}$$

$$\frac{(7-4)\times10^{-3}}{3.5-2} = \frac{(680\times10^{-9})}{a}$$

$$a = 3.4\times10^{-4}$$

a = 3.4×10^{-4} m [3]

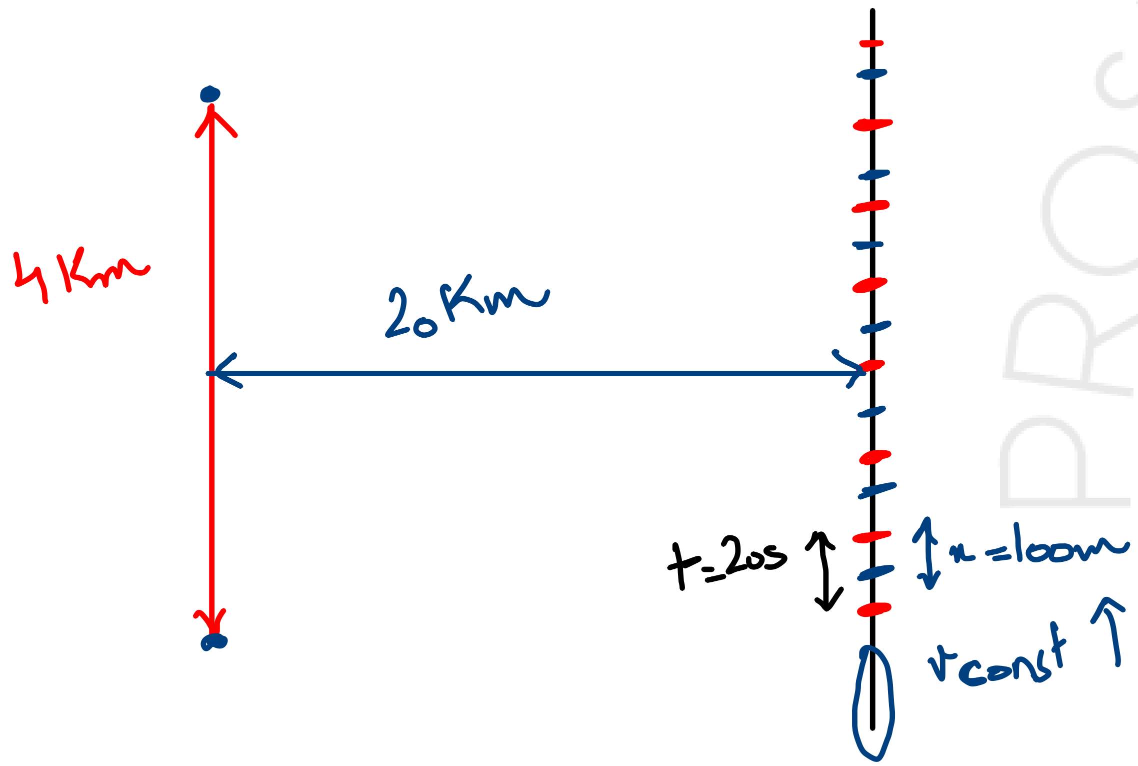
(ii) The laser is now replaced by another laser that emits light of a shorter wavelength. $\lambda\downarrow$

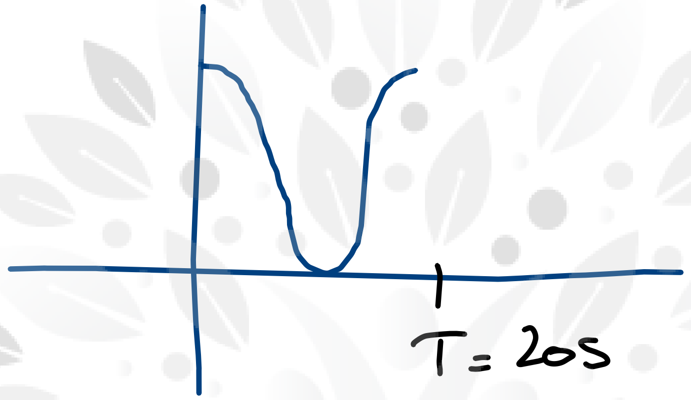
On Fig. 5.2, sketch a possible line to show the variation with D of x for the fringes that are now produced. [2]

[Total: 10]

A 15 MHz signal is sent coherently from a pair of two antennas to a nearby train track , 20 km away such that they interfere over the region and meet at the railway track. The antennas are 4 km apart.
A maglev (magnetic levitation) train crosses the track and is equipped with an antenna which is connected to a CRO that receives frequency.

This train crosses the interference pattern at a constant speed "v". The CRO receives a frequency of 0.05 Hz. Calculate the speed "v" with which the train passes through.





$$\downarrow x = \frac{\lambda D}{a \uparrow}$$

$$f = 0.05\ Hz$$

$$T = \frac{1}{0.05} = 20s$$

$$v = f\lambda \Rightarrow (3\times10^8) = (15\times10^6)\,\lambda$$

$$\lambda = 20\ m$$

$$x = \frac{\lambda D}{a} \Rightarrow \frac{(20\times\cancel{10^3})\times20}{(4\times\cancel{10^3})} = 100\,m$$

$$v = \frac{d}{t} = \frac{100}{20} = 5\,ms^{-1}$$

Stationary Waves:- (they can be longitudinal and transverse waves)

These waves don't transfer energy, they are also known as standing waves.

Conditions:-

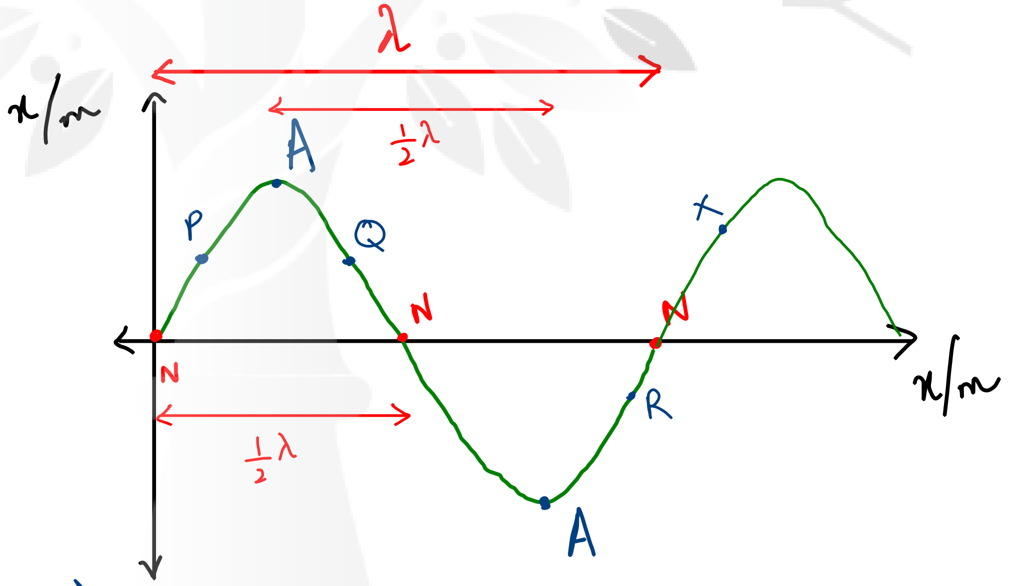
- same frequency
- same wavelength
- same velocity

→

Describe the formation of a stationary wave:-

- one wave travels forwards
- another wave travels backwards (mostly achieved by reflection)
- both waves superpose

For stationary waves only:-



Nodes:- Points of minimum or zero displacement
Antinodes:- Points of maximum displacement

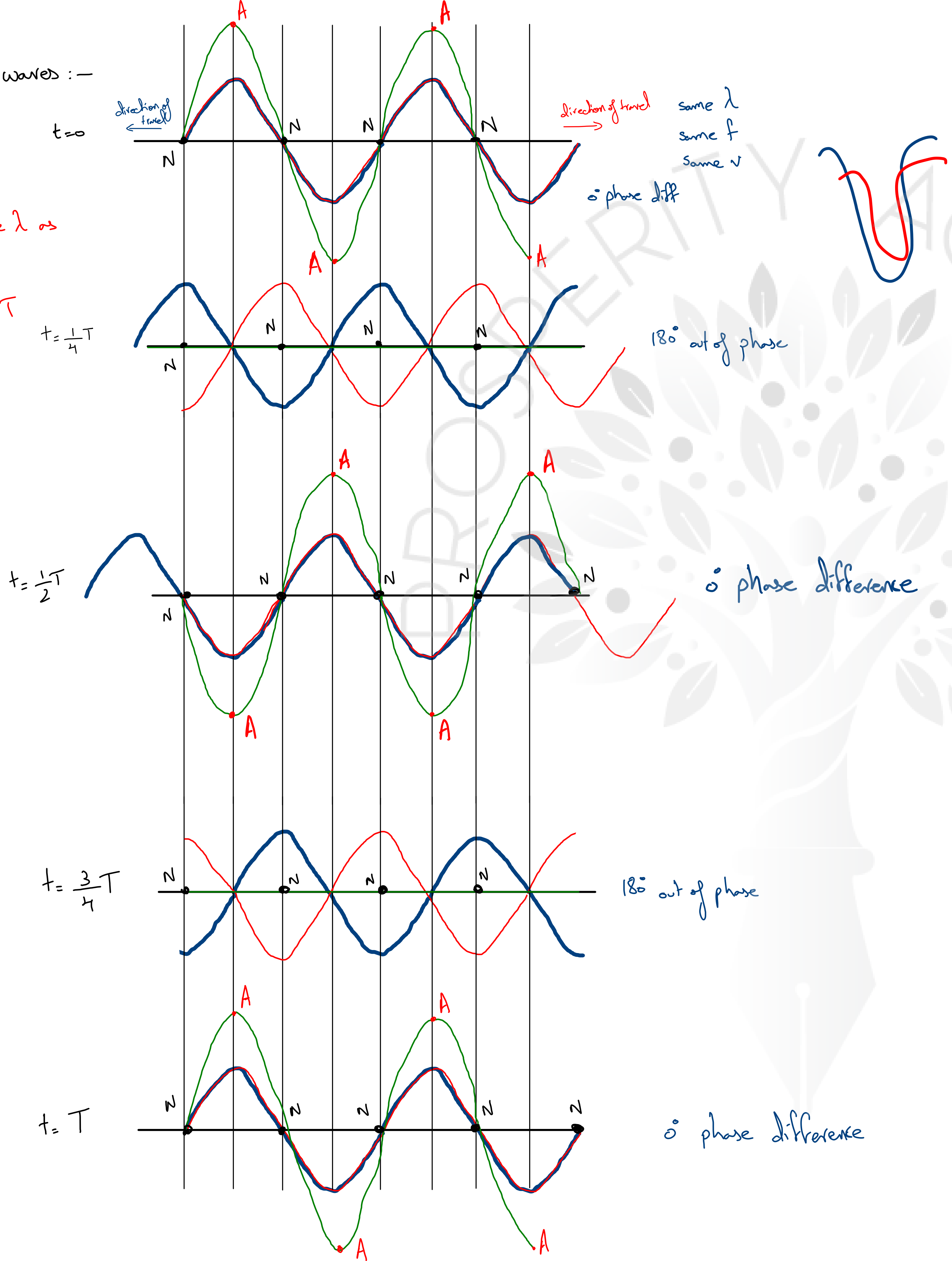
The distance b/w 2 nodes/antinodes is $\frac{1}{2}\lambda$

The phase difference in a loop is 0° (P & Q & X are 0° out of phase)

The phase difference in opposite loops is 180° (X & R are 180° out of phase)

Formation of Stationary waves :–

- Stationary wave has the same λ as the individual waves
- stationary waves have the same T as the individual waves

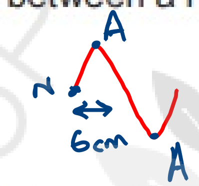


6 (a) Describe the conditions required for two waves to be able to form a stationary wave.

One wave must travel in one direction, while the other travels in the opposite direction. They must be of the same nature, wavelength, velocity and frequency. As the waves pass through each other, they will superpose and form a stationary wave [2]

(b) A stationary wave on a string has nodes and antinodes. The distance between a node and an adjacent antinode is 6.0 cm.

(i) State what is meant by a *node*.



A point of minimum displacement [1]

(ii) Calculate the wavelength of the two waves forming the stationary wave.

$N \rightarrow A = \frac{1}{4}\lambda$

$6cm = \frac{1}{4}\lambda$

$\lambda = 24 cm$

wavelength = 24 cm [1]

(iii) State the phase difference between the particles at two adjacent antinodes of the stationary wave.

phase difference = 180 ° [1]

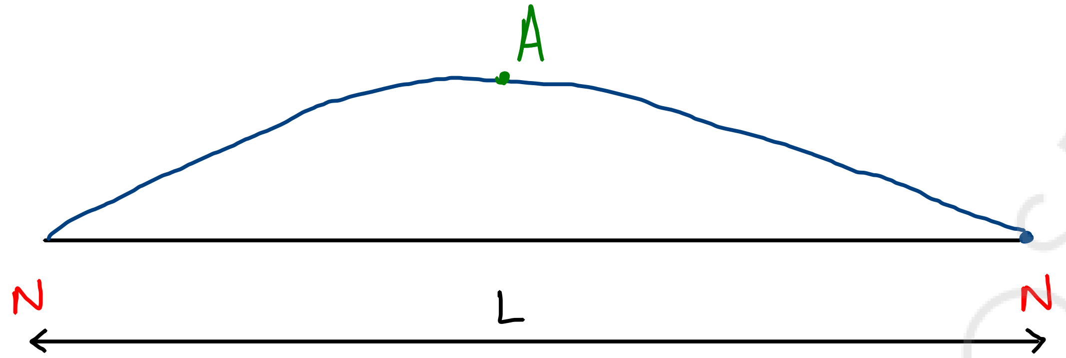
[Total: 5]

Stationary waves between nodes:-

(At the point of reflection, you always have a node)

On a stretched rope

①



1st harmonic (smallest f of stationary wave)
(fundamental frequency)

$\frac{1}{2}\lambda = L$

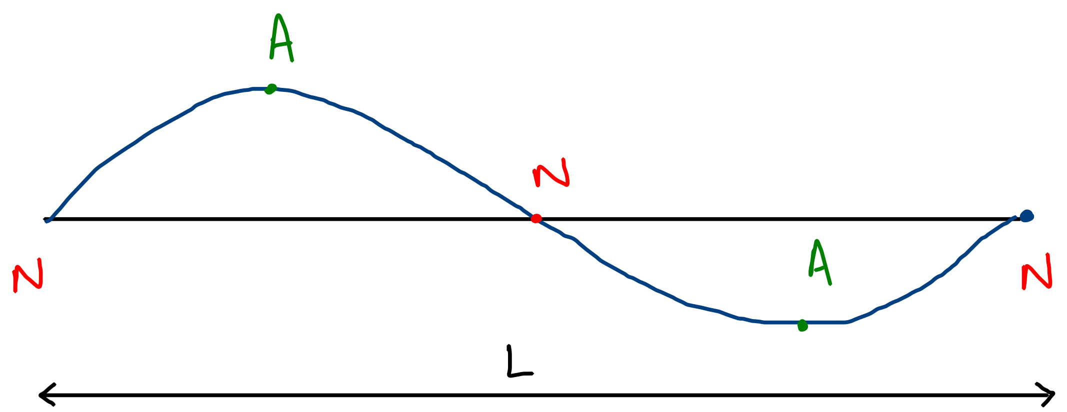
$\lambda = 2L$

$v = f\lambda$

$v = f(2L)$

$f_1 = \frac{v}{2L}$

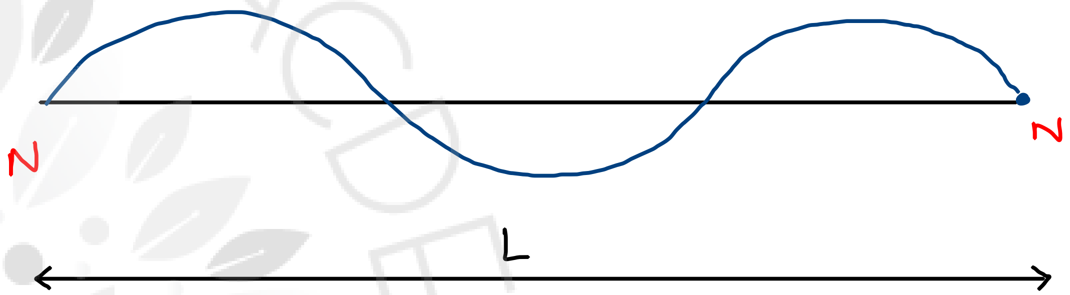
②



$\lambda = L$

$f_2 = \frac{v}{L}$

③



$\frac{3}{2}\lambda = L$

$\lambda = \frac{2L}{3}$

$f_3 = \frac{v}{2L/3} \Rightarrow \frac{3v}{2L}$

$\lambda_n = \frac{2L}{n}$

$f_n = \frac{nv}{2L}$

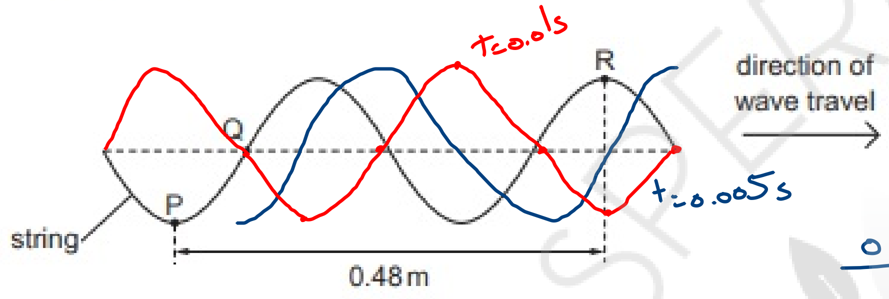
(where n is the harmonic)

4 (a) State the difference between progressive waves and stationary waves in terms of the transfer of energy along the wave.

Progressive waves transfer energy while stationary waves donot.

[1]

(b) A progressive wave travels from left to right along a stretched string. Fig. 4.1 shows part of the string at one instant.



$\frac{0.02}{4} = 0.005$

Fig. 4.1

P, Q and R are three different points on the string. The distance between P and R is 0.48 m. The wave has a period of 0.020 s.

(i) Use Fig. 4.1 to determine the wavelength of the wave.

$6 \times \frac{\lambda}{4} = 0.48 \Rightarrow \lambda = 0.32$

wavelength = 0.32 m [1]

(ii) Calculate the speed of the wave.

$v = f\lambda$

$v = \left(\frac{1}{0.02}\right)(0.32)$

speed = 16 m s^{-1} [2]

(iii) Determine the phase difference between points Q and R.

45° or 90°

$\frac{\Delta x}{\lambda} \times 360° \Rightarrow \frac{1.25 \times 0.32}{0.32} \times 360° = 450°$

(iv) Fig. 4.1 shows the position of the string at time $t = 0$. Describe how the displacement of point Q on the string varies with time from $t = 0$ to $t = 0.010$ s.

Q will go to a minimum displacement at $t = 0.005$s.
Q will then return to its original displacement at 0.01s.

[2]

(c) A stationary wave is formed on a different string that is stretched between two fixed points X and Y. Fig. 4.2 shows the position of the string when each point is at its maximum displacement.

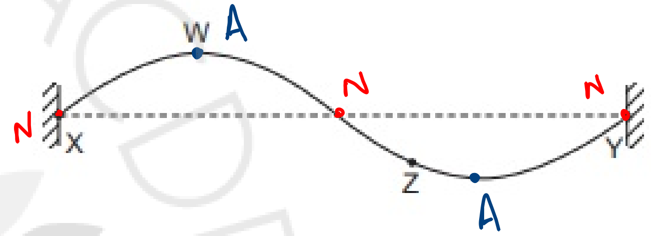


Fig. 4.2

(i) Explain what is meant by a *node* of a stationary wave.

Point of minimum displacement [1]

(ii) State the number of antinodes of the wave shown in Fig. 4.2.

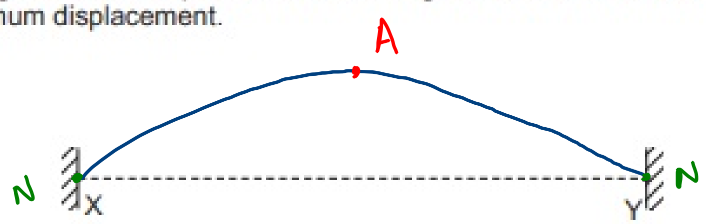
number = 2 [1]

(iii) State the phase difference between points W and Z on the string.

phase difference = 180° [1]

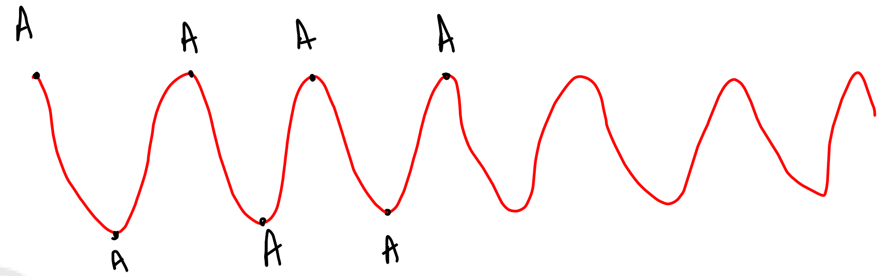
(iv) A new stationary wave is now formed on the string. The new wave has a frequency that is half of the frequency of the wave shown in Fig. 4.2. The speed of the wave is unchanged.

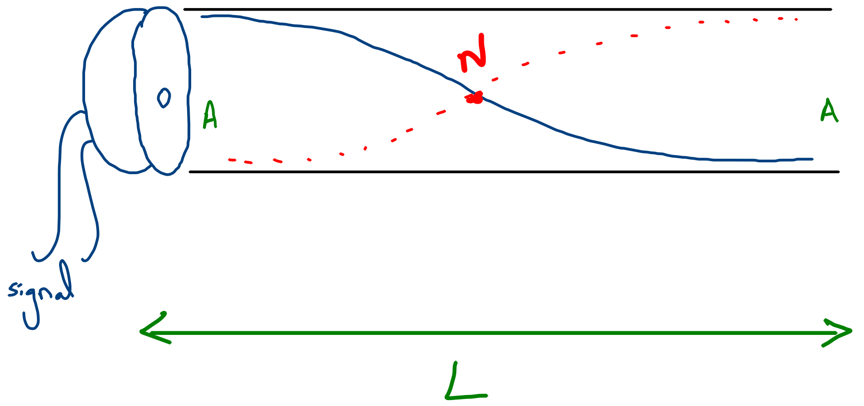
On Fig. 4.3, draw a position of the string, for this new wave, when each point is at its maximum displacement.



(1)

Stationary waves between 2 antinodes :- (At the source of the wave, you always have an antinode)

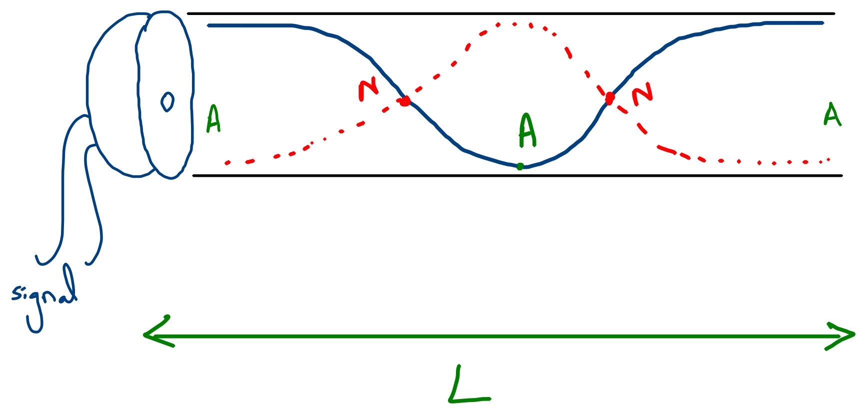




1st harmonic (fundamental frequency)

$\frac{\lambda}{2} = L \Rightarrow \lambda = 2L$

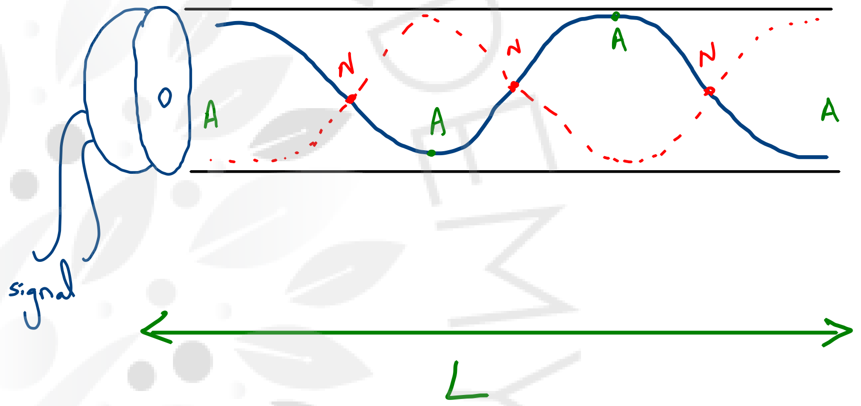
$f = \frac{v}{\lambda} \Rightarrow f_1 = \frac{v}{2L}$



2nd harmonic

$\lambda = L$

$f_2 = \frac{v}{L}$



3rd harmonic

$6 \times \frac{\lambda}{4} = L \Rightarrow \lambda = \frac{2L}{3}$

$f_3 = \frac{v}{\frac{2}{3}L} \Rightarrow f_3 = \frac{3v}{2L}$

$\lambda_n = \frac{2L}{n}$

$f_n = \frac{nv}{2L}$

5 A vertical tube of length 0.60 m is open at both ends, as shown in Fig. 5.1.

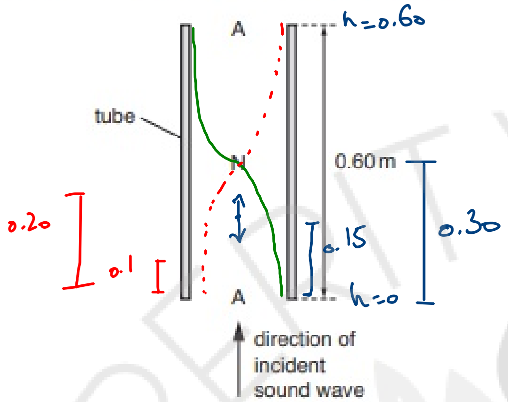


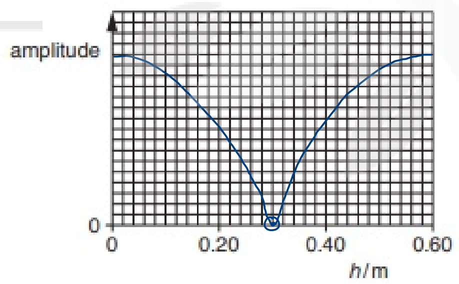
Fig. 5.1

An incident sinusoidal sound wave of a single frequency travels up the tube. A stationary wave is then formed in the air column in the tube with antinodes A at both ends and a node N at the midpoint.

(a) Explain how the stationary wave is formed from the incident sound wave.

The wave travels upwards. The wave reflects and then enters the tube again. Due to the 2 waves having same frequency, wavelength and velocity they superpose and form a stationary wave [2]

(b) On Fig. 5.2, sketch a graph to show the variation of the amplitude of the stationary wave with height h above the bottom of the tube.



(c) For the stationary wave, state:

(i) the direction of the oscillations of an air particle at a height of 0.15 m above the bottom of the tube

up and down [1]

(ii) the phase difference between the oscillations of a particle at a height of 0.10 m and a particle at a height of 0.20 m above the bottom of the tube.

phase difference = 0 ° [1]

(d) The speed of the sound wave is 340 m s^{-1}.

Calculate the frequency of the sound wave.

$v = f\lambda$

$340 = f(1.2)$

$f = 283.33\,Hz$

$\frac{1}{2}\lambda = 0.60$

$\lambda = 1.2\,m$

frequency = 280 Hz [2]

(e) The frequency of the sound wave is gradually increased.

Determine the frequency of the wave when a stationary wave is next formed.

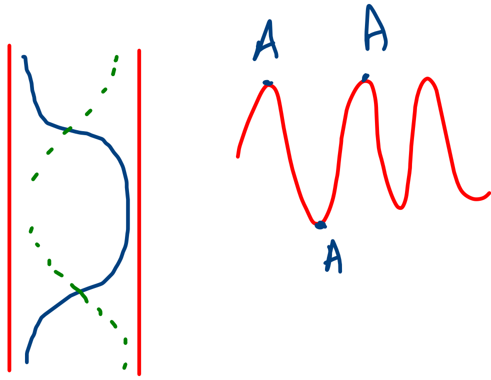
$\lambda = 0.60$

$v = f\lambda$

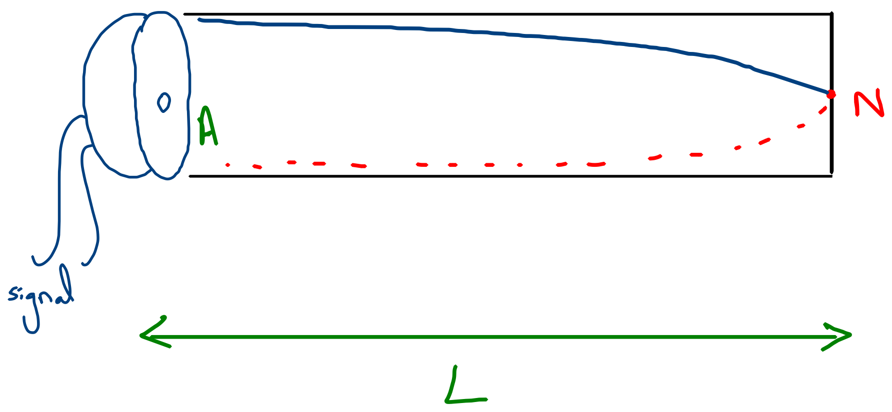
$\frac{340}{0.60} = f \Rightarrow f_2 = 566$

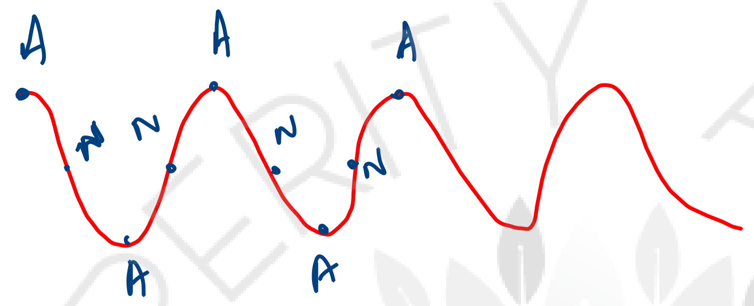
frequency = 570 Hz [1]

[Total: 9]



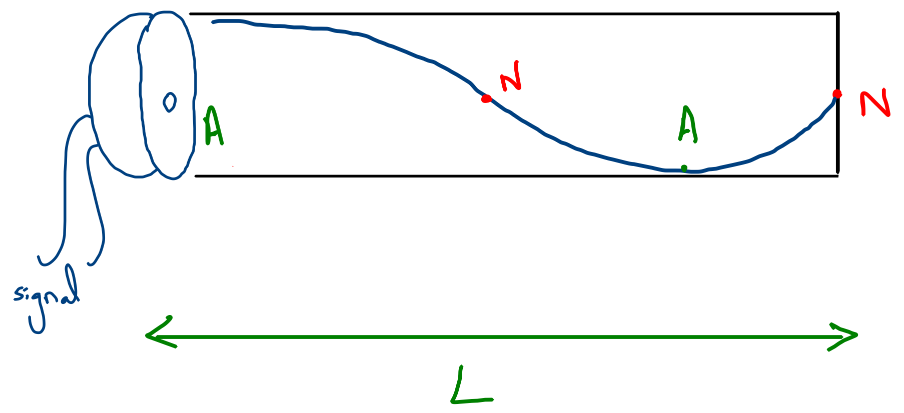
Stationary waves between an antinode and a node:-





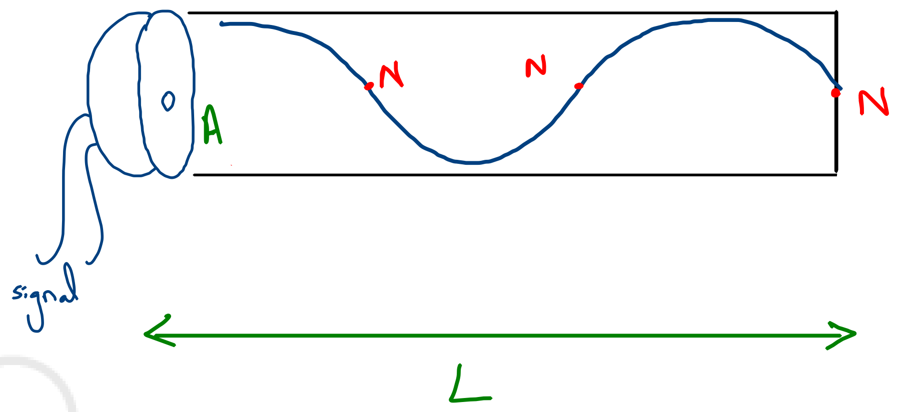
1st harmonic (fundamental frequency)

$$\frac{\lambda}{4} = L \Rightarrow \lambda = 4L \qquad f_1 = \frac{v}{4L}$$



2nd harmonic

$$\frac{3\lambda}{4} = L \Rightarrow \lambda = \frac{4L}{3} \qquad f_2 = \frac{v}{4L/3} \Rightarrow f_2 = \frac{3v}{4L}$$



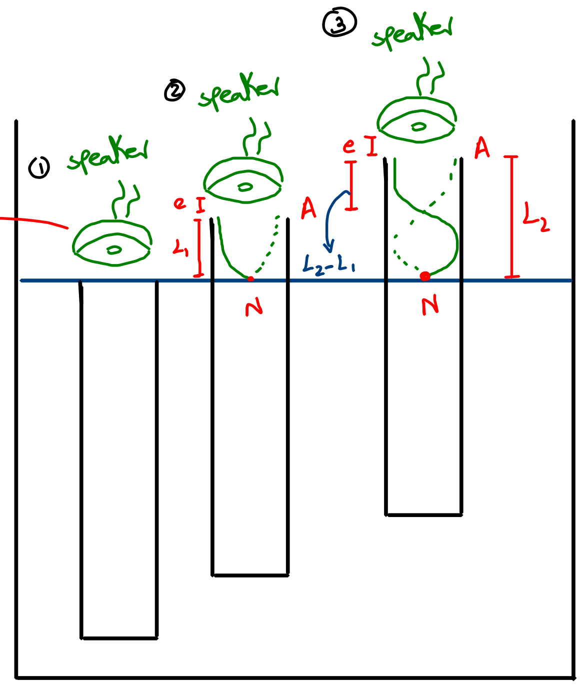
3rd harmonic:-

$$\frac{5\lambda}{4} = L \Rightarrow \lambda = \frac{4L}{5} \qquad f_3 = \frac{v}{\frac{4L}{5}} \Rightarrow \frac{5v}{4L}$$

$$\lambda_n = \frac{4L}{2n-1} \qquad f_n = \frac{(2n-1)v}{4L}$$

Working out the speed of sound using a water column:-

play a constant Known frequency (you can also use a tuning fork)



e: end correction

$$\frac{\lambda}{4} = L_1 + e$$

$$e = \frac{\lambda}{4} - L_1$$

$$\frac{3\lambda}{4} = L_2 + e$$

$$\frac{3\lambda}{4} = L_2 + \frac{\lambda}{4} - L_1$$

$$\boxed{\frac{\lambda}{2} = L_2 - L_1}$$

$$v = f\lambda$$

$$v = f\left[2(L_2 - L_1)\right]$$

6 A long tube, fitted with a tap, is filled with water. A tuning fork is sounded above the top of the tube as the water is allowed to run out of the tube, as shown in Fig. 6.1.

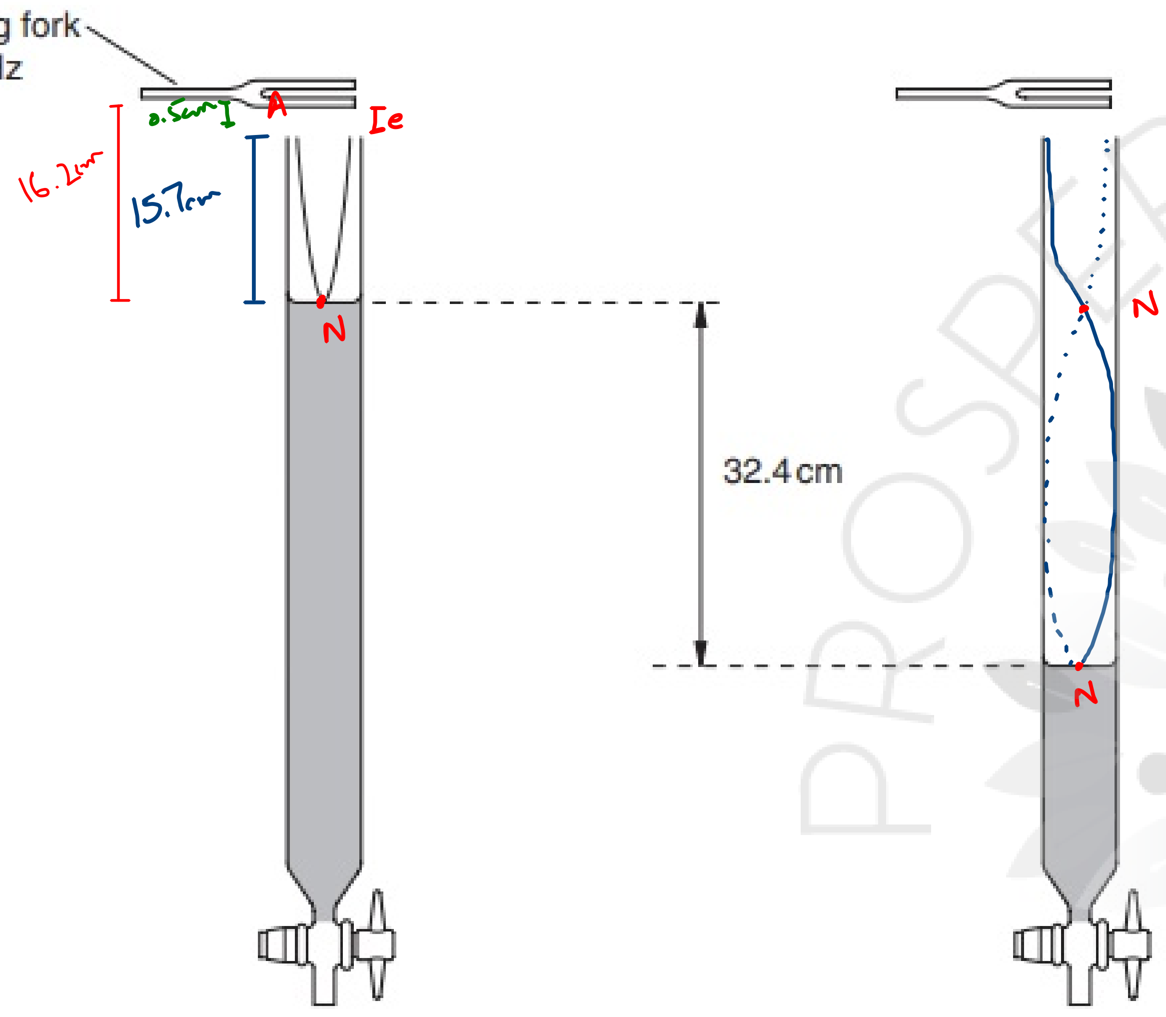


Fig. 6.1 Fig. 6.2

A loud sound is first heard when the water level is as shown in Fig. 6.1, and then again when the water level is as shown in Fig. 6.2.

Fig. 6.1 illustrates the stationary wave produced in the tube.

(a) On Fig. 6.2,

(i) sketch the form of the stationary wave set up in the tube, [1]

(ii) mark, with the letter N, the positions of any nodes of the stationary wave. [1]

(b) The frequency of the fork is 512 Hz and the difference in the height of the water level for the two positions where a loud sound is heard is 32.4 cm.

Calculate the speed of sound in the tube.

$32.4 \times 10^{-2} = \frac{1}{2}\lambda$

$\lambda = 64.8 \times 10^{-2}$

$v = f\lambda$

$v = (512)(64.8 \times 10^{-2})$

$v = 331.776$

speed = ...332........ $m\,s^{-1}$ [3]

(c) The length of the column of air in the tube in Fig. 6.1 is 15.7 cm.

Suggest where the antinode of the stationary wave produced in the tube in Fig. 6.1 is likely to be found.

The antinode is most likely $16.2\,cm - 15.7\,cm = 0.5\,cm$ above the end of the tube.

.... [2]

$\lambda = 64.8\,cm$

$\frac{\lambda}{4} = 16.2\,cm$

6 A hollow tube is used to investigate stationary waves. The tube is closed at one end and open at the other end. A loudspeaker connected to a signal generator is placed near the open end of the tube, as shown in Fig. 6.1.

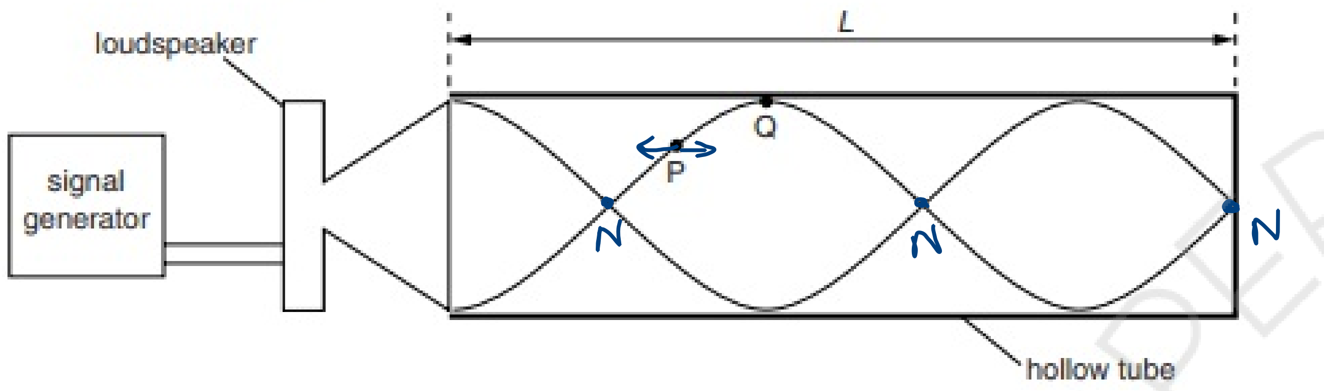


Fig. 6.1

The tube has length L. The frequency of the signal generator is adjusted so that the loudspeaker produces a progressive wave of frequency 440 Hz. A stationary wave is formed in the tube. A representation of this stationary wave is shown in Fig. 6.1.
Two points P and Q on the stationary wave are labelled.

(a) **(i)** Describe, in terms of energy transfer, the difference between a progressive wave and a stationary wave.

Progressive waves transfer energy while stationary waves donot [1]

(ii) Explain how the stationary wave is formed in the tube.

The wave travels forward and gets reflected and then travels in the opposite direction. The incident and reflected wave then superpose and create a stationary wave as they have the same wavelength, frequency and velocity [3]

(iii) State the direction of the oscillations of an air particle at point P.

left right

[1]

(b) On Fig. 6.1 label, with the letter N, the nodes of the stationary wave. [1]

(c) State the phase difference between points P and Q on the stationary wave.

phase difference = $0°$ [1]

(d) The speed of sound in the tube is $330\,\mathrm{m\,s^{-1}}$.

Calculate

(i) the wavelength of the sound wave,

$v = f\lambda$

$330 = 440\lambda$

$\lambda = 0.75$

wavelength = 0.75 m [2]

(ii) the length L of the tube.

$5 \times \frac{\lambda}{4} \Rightarrow \frac{5}{4} \times 0.75 = 0.9375$

length = 0.94 m [2]

4 **(a)** State the principle of superposition.

When 2 waves of the same nature meet at a point, the resultant amplitude is the algebraic sum of the individual amplitudes. [2]

(b) A transmitter produces microwaves that travel in air towards a metal plate, as shown in Fig. 4.1.

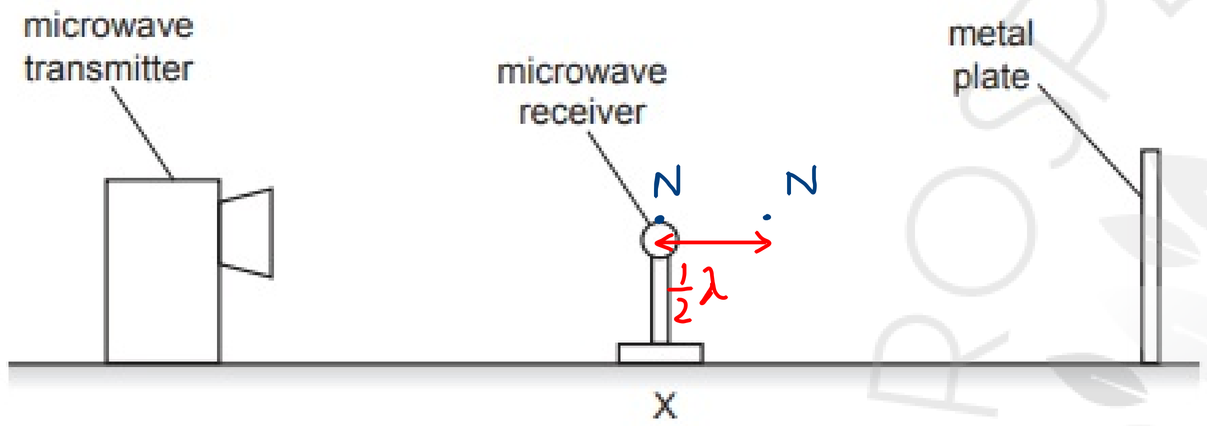


Fig. 4.1

The microwaves have a wavelength of 0.040 m. A stationary wave is formed between the transmitter and the plate.

(i) Explain the function of the metal plate.

It is acting as a reflector. [1]

(ii) Calculate the frequency, in GHz, of the microwaves.

$v = f\lambda$

$3\times10^8 = f(0.040)$

$f = 7.5\times10^9 = 7.5\ \text{GHz}$

(iii) A microwave receiver is initially placed at position X where it detects an intensity minimum. The receiver is then slowly moved away from X directly towards the plate.

1. Determine the shortest distance from X of the receiver when it detects another intensity minimum.

distance = 0.020 m /2cm

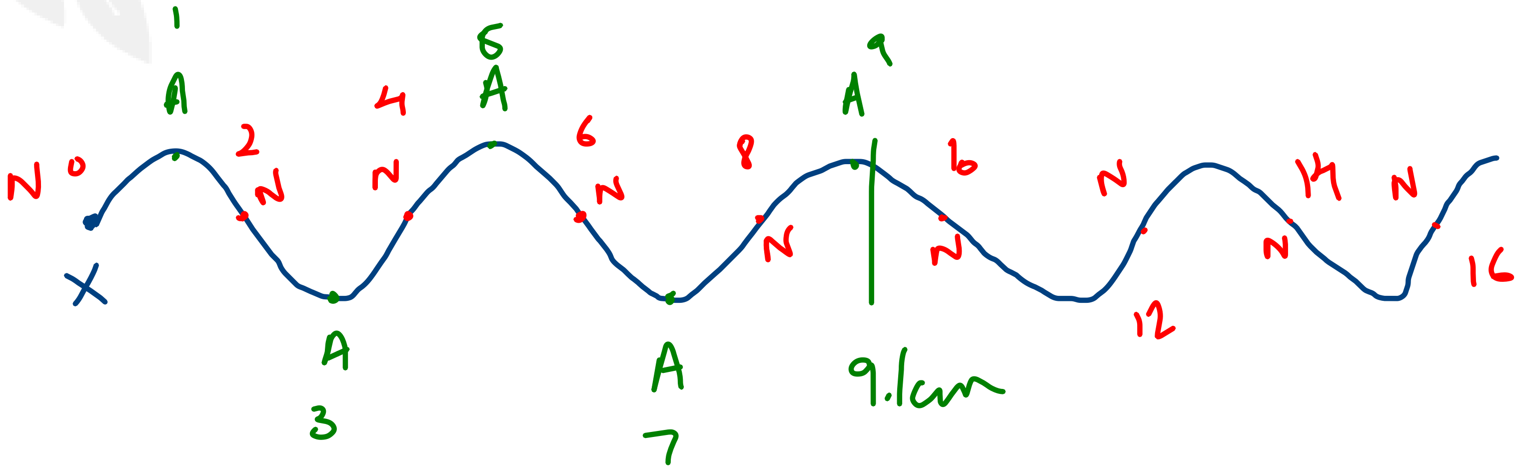
Antinode

2. Determine the number of intensity maxima that are detected by the receiver as it moves from X to a position that is 9.1 cm away from X.

number = 5

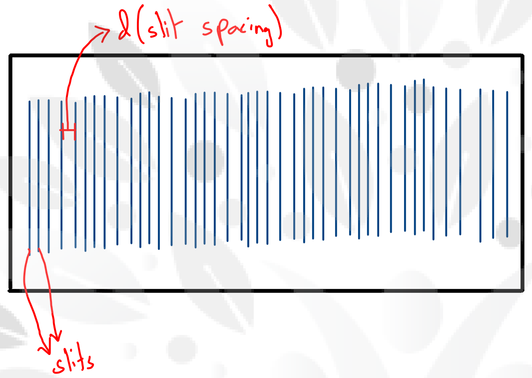
[2]

[Total: 8]



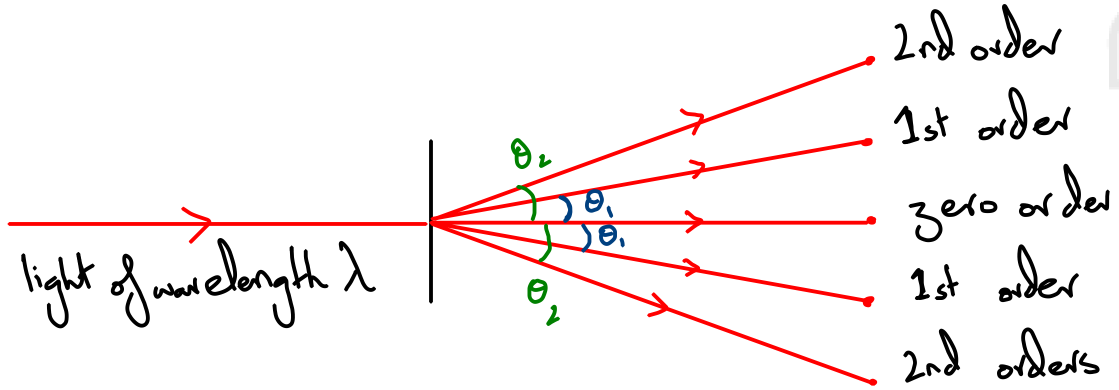
Diffraction Grating :- An instrument containing many slits and helps to find out wavelength of light through diffraction.

Diffraction :- Spreading of wave into its geometric shadow as it passes through an edge or a slit.



diffraction is most significant when

slit size $\simeq$ wavelength



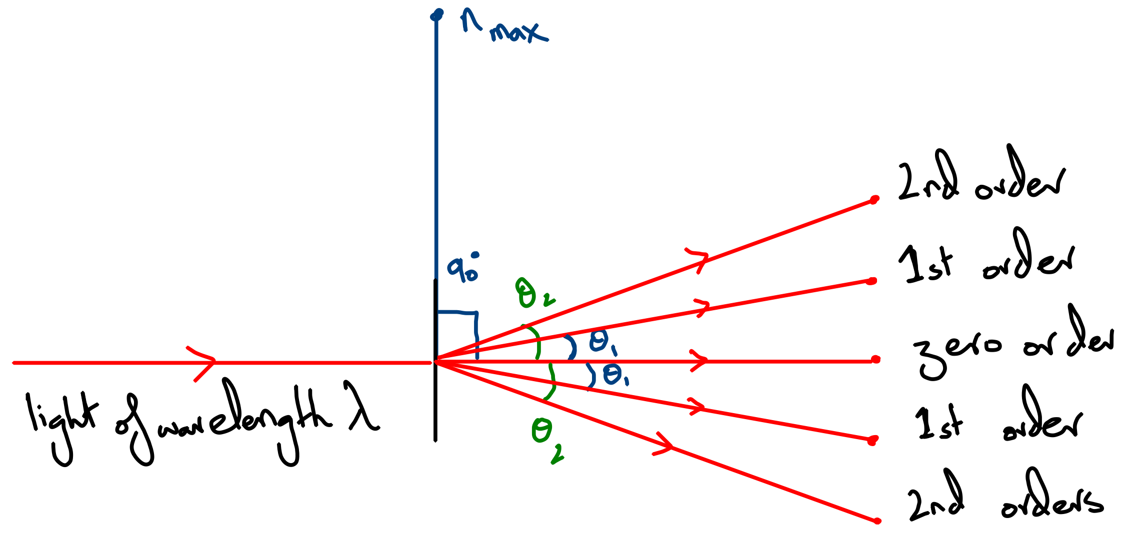
$d \sin\theta = n\lambda$ (only works if incident light is normal)

λ : incident wavelength

n : order number

θ : angle between the n^{th} and zero order

d : slit spacing



$d\sin\theta = n\lambda$

$d(\sin 90) = n_{max}\lambda$

$\hookrightarrow 1$

$n_{max} = \dfrac{d}{\lambda}$

(round down)

Total orders $= 2n_{max} + 1$

(b) Light of wavelength 590 nm is incident normally on a diffraction grating having 750 lines per millimetre.
The diffraction grating formula may be expressed in the form

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

(i) Calculate the value of d, in metres, for this grating.

$750 : 1\times10^{-3}$

$x : 1$

$x = \dfrac{750}{1\times10^{-3}} = 750\,000$ lines per meter

$750\,000 : 1m$

$1 : d$

$d = \dfrac{1}{750\,000}$

(ii) Determine the maximum value of n for the light incident normally on the grating.

$d\sin\theta = n\lambda$

$d\sin 90 = n_{max}\lambda$

$n_{max} = \dfrac{d}{\lambda} = \dfrac{1}{750000} \div (590\times10^{-9})$

$= 2.26$

$\hookrightarrow$ round down $\simeq 2$

(iii) Total orders: $2(2)+1 = 5$

(b) A beam of light of a single wavelength is incident normally on a diffraction grating, as illustrated in Fig. 5.2.

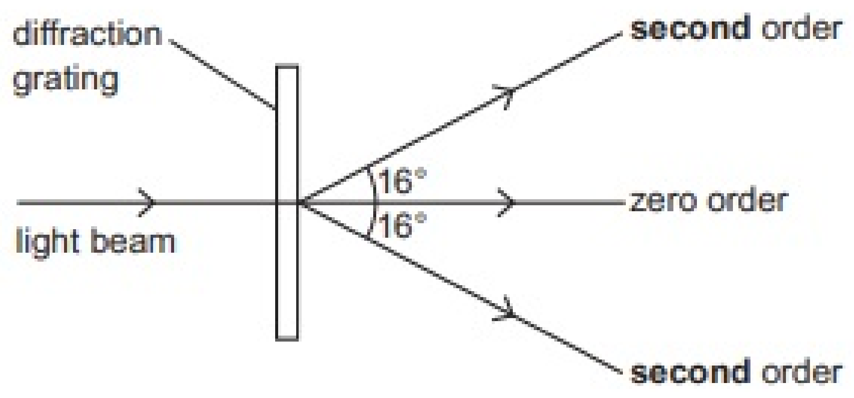


Fig. 5.2 (not to scale)

Fig. 5.2 does not show all of the emerging beams from the grating. The angle between the **second**-order emerging beam and the central zero-order beam is 16°. The grating has a line spacing of 3.4×10^{-6} m. d

(i) Calculate the wavelength of the light.

$d\sin\theta = n\lambda$

$(3.4\times10^{-6})\sin16 = 2\lambda \Rightarrow 4.68\times10^{-7}$

wavelength = 4.7×10^{-7} m [2]

(ii) Determine the highest order of emerging beam from the grating.

$(3.4\times10^{-6})\sin90 = n_{max}(4.7\times10^{-7})$

$n_{max} = \dfrac{3.4\times10^{-6}}{4.7\times10^{-7}} \simeq 7.23$

highest order = 7 [2]

[Total: 9]

4 (a) For a progressive water wave, state what is meant by:

(i) *displacement*

distance moved by a particle from its mean position in a specific linear direction (+ve & -ve) [1]

(ii) *amplitude*.

maximum displacement moved by a particle from its mean position (+ve only) [1]

(b) Two coherent waves X and Y meet at a point and superpose. The phase difference between the waves at the point is 180°. Wave X has an amplitude of 1.2 cm and intensity I. Wave Y has an amplitude of 3.6 cm. ↳ destructive interference

Calculate, in terms of I, the resultant intensity at the meeting point.

$$\frac{I_1}{a_1^2} = \frac{I_2}{a_2^2}$$

$$\frac{I}{(1.2)^2} = \frac{I_2}{(3.6-1.2)^2}$$

$$I_2 = \frac{I(3.6-1.2)^2}{(1.2)^2}$$

$$I_2 = 4I$$

intensity = 4.0 I [2]

(c) (i) Monochromatic light is incident on a diffraction grating. Describe the diffraction of the light waves as they pass through the grating.

As the light passes through the slit, it spreads into its geometric shadow. [2]

(ii) A parallel beam of light consists of two wavelengths 540 nm and 630 nm. The light is incident normally on a diffraction grating. Third-order diffraction maxima are produced for each of the two wavelengths. No higher orders are produced for either wavelength.

Determine the smallest possible line spacing d of the diffraction grating.

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

$$d \sin 90 = 3\lambda$$

$$d = 3\lambda$$

$$\downarrow d \propto \downarrow \lambda$$

$$d = 3(540 \times 10^{-9}) = 1.62 \times 10^{-6}$$ ✗

$$d = 3(630 \times 10^{-9}) = 1.89 \times 10^{-6}$$ ✓

d = 1.9×10^{-6} m [3]

(iii) The beam of light in **(c)(ii)** is replaced by a beam of blue light incident on the same diffraction grating.

$\lambda = 400/450$ nm

State and explain whether a third-order diffraction maximum is produced for this blue light.

Yes a third order maximum will be formed as the wavelength of blue light is approximately 450 nm. [2]

[Total: 11]

4 **(a)** For a progressive wave, state what is meant by *wavelength*.

It is the distance between 2 successive points in phase [1]

(b) A light wave from a laser has a wavelength of 460 nm in a vacuum.

Calculate the period of the wave.

$v = \left(\frac{1}{T}\right)\lambda$

$T = \frac{\lambda}{v} = \frac{460 \times 10^{-9}}{3 \times 10^{8}} = 1.53 \times 10^{-15}$

period = 1.5×10^{-15} s [3]

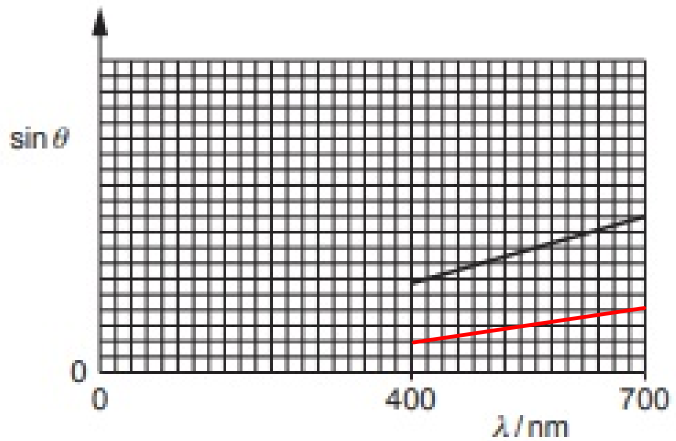
(c) The light from the laser is incident normally on a diffraction grating.

Describe the diffraction of the light waves at the grating.

As the light passes through the slit, it spreads into its geometric shadow.

[2]

(d) A diffraction grating is used with different wavelengths of visible light. The angle θ of the **fourth-order maximum** from the zero-order (central) maximum is measured for each wavelength. The variation with wavelength λ of $\sin\theta$ is shown in Fig. 4.1.



(i) The gradient of the graph is G.

Determine an expression, in terms of G, for the distance d between the centres of two adjacent slits in the diffraction grating.

$d\sin\theta = n\lambda$

$\sin\theta = \frac{n}{d} \times \lambda$

$y = m x$

$G = \frac{4}{d}$

$d = \frac{4}{G}$

d = $4/G$ [2]

(ii) On Fig. 4.1, sketch a graph to show the results that would be obtained for the **second**-order maxima. [2]

[Total: 10]

$\downarrow \sin\theta = \frac{\downarrow n}{d}\lambda$

$\downarrow m = \frac{\downarrow n}{d}$