



SUPERPOSITION

PHYSICS BY

Kasim Hashid

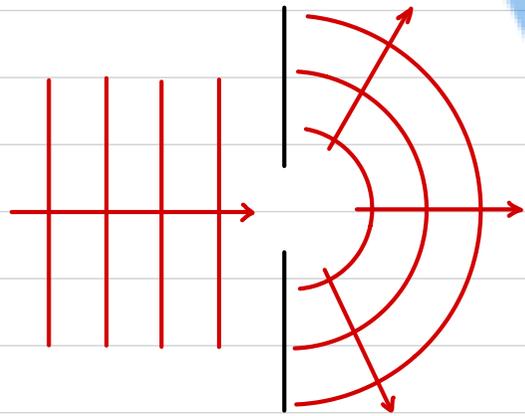
Diffraction of Waves

- The spreading of the wave as it passes through a slit or over an edge.
- During diffraction, energy of the wave spreads out and its intensity falls.

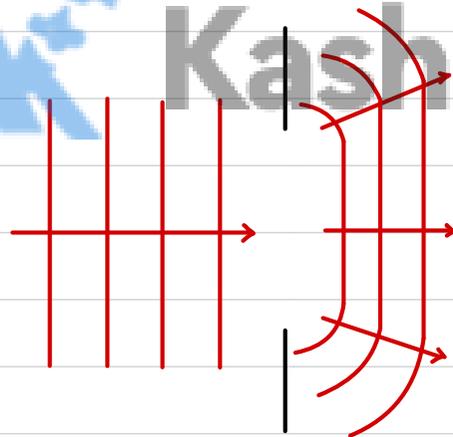


PHYSICS BY

Kashan Rashid



slit size \approx wavelength
Max Diffraction



slit size $>$ wavelength
less Diffraction

Interference

When two or more waves meet at a point, they overlap one another to produce a new resultant wave.

Conditions for interference

1. Waves must meet at a point.
2. Waves must have the same nature i.e. both mechanical or both electromagnetic
3. Waves should have same frequency (Small difference in frequency can still cause interference)

Principle of Superposition

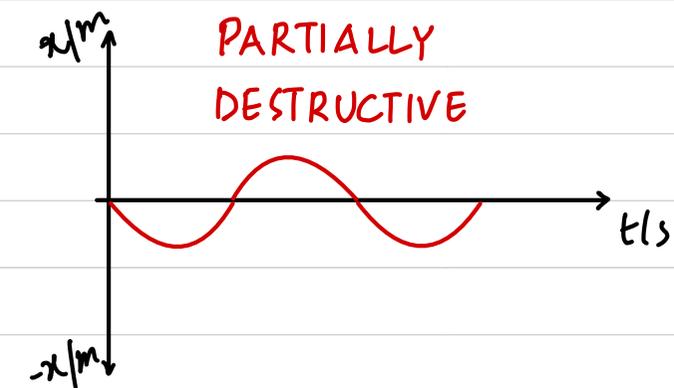
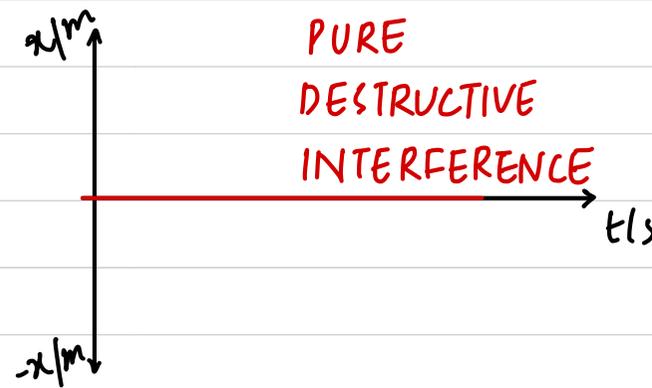
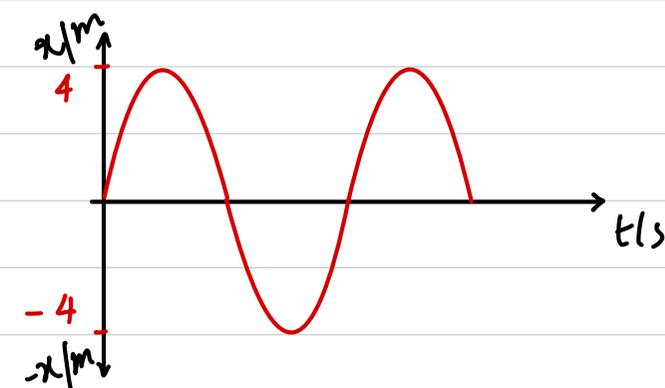
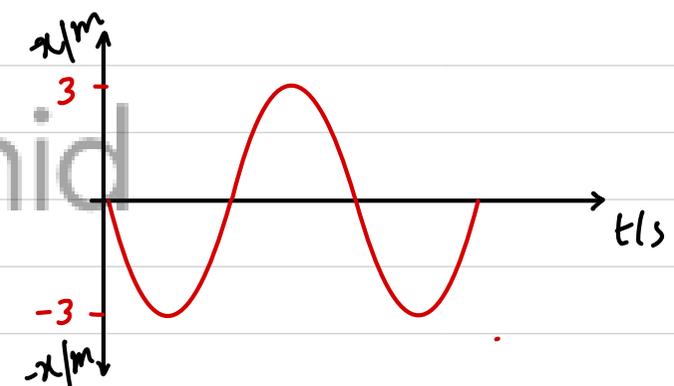
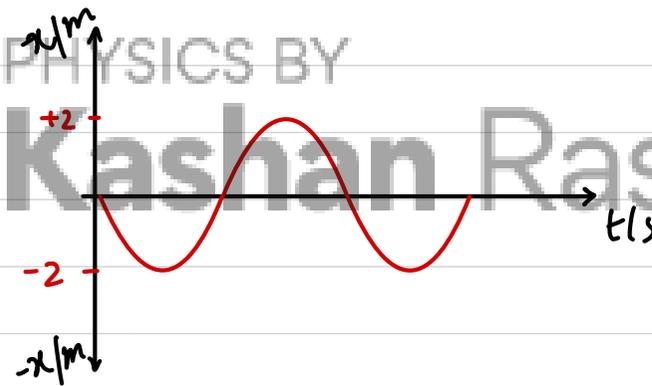
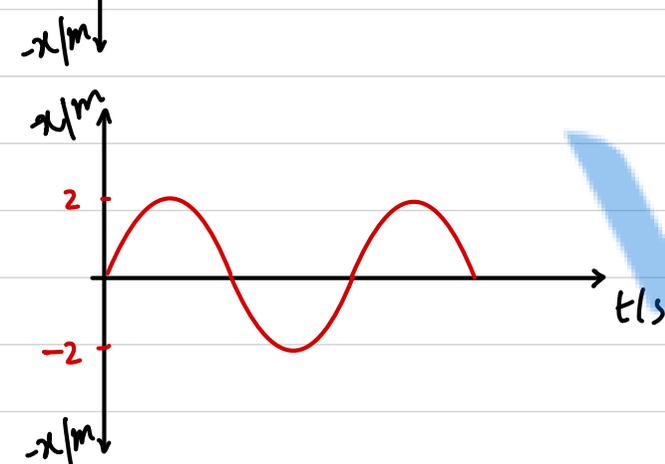
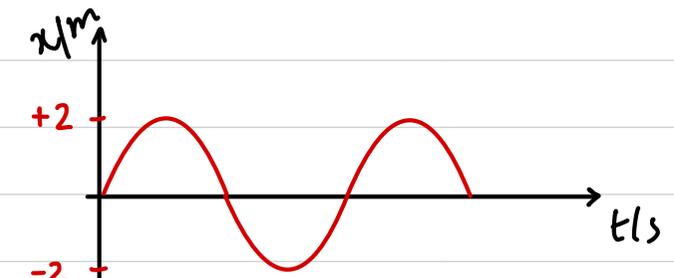
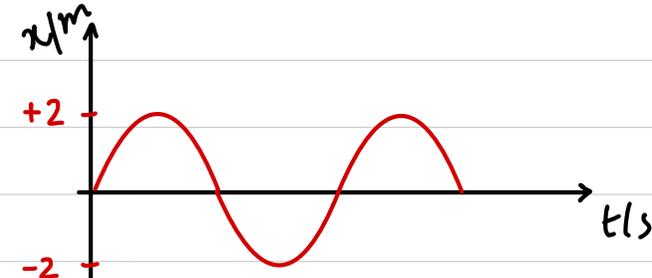
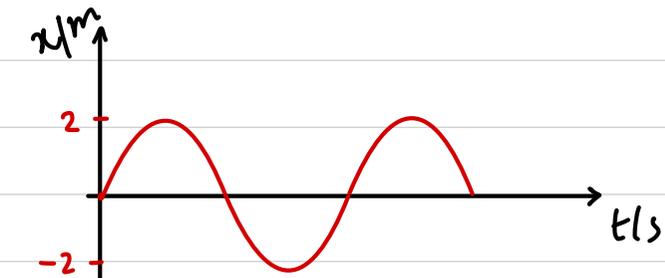
When two waves meet at a point in space, the resultant displacements of new wave is algebraic sum of displacements of interfering waves.

3 types of Interference

1. Constructive Interference
2. Destructive Interference
3. Intermediate Interference

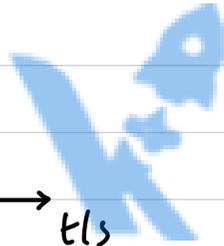
Constructive Interference

Destructive Interference



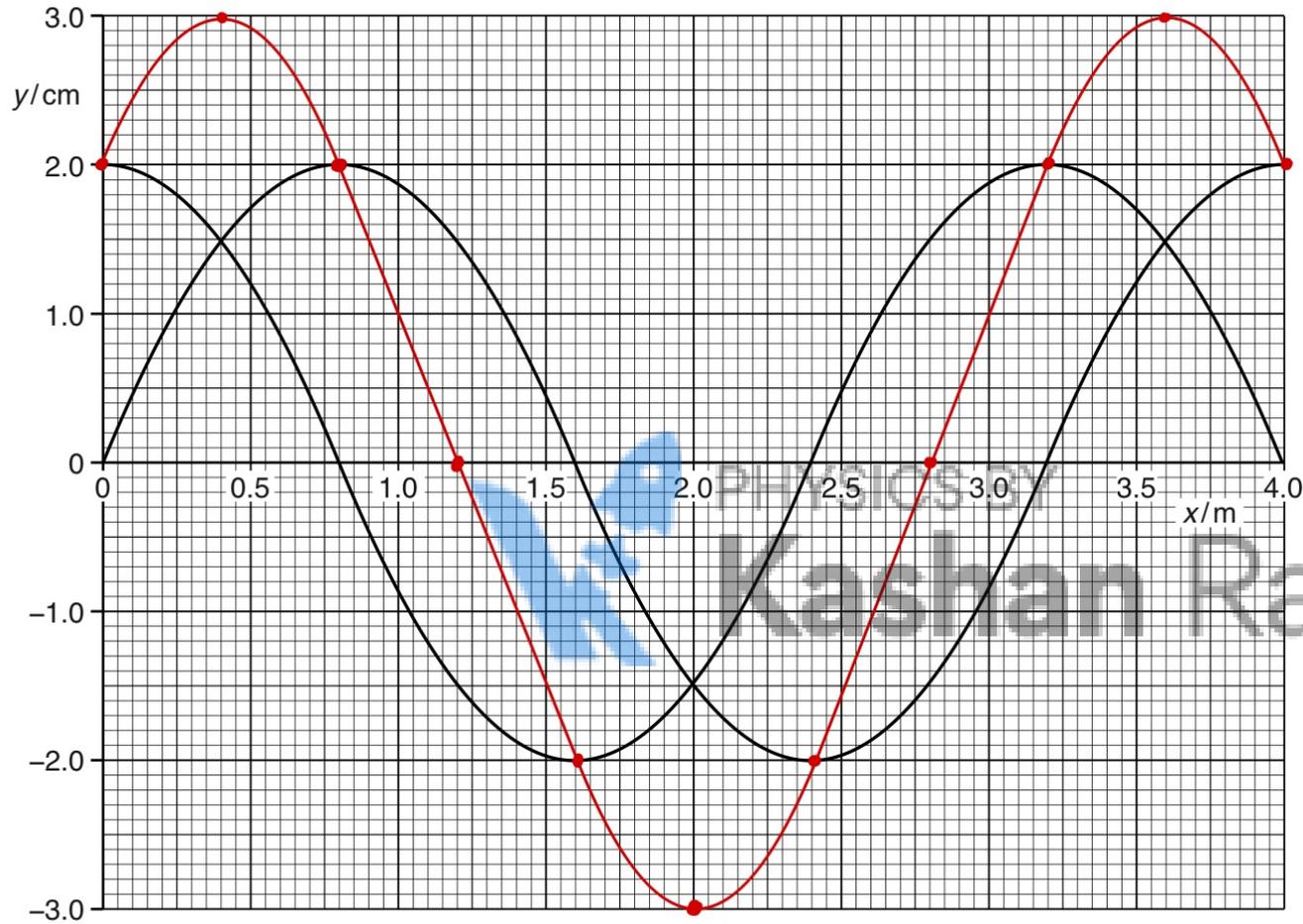
PURE
DESTRUCTIVE
INTERFERENCE

PARTIALLY
DESTRUCTIVE



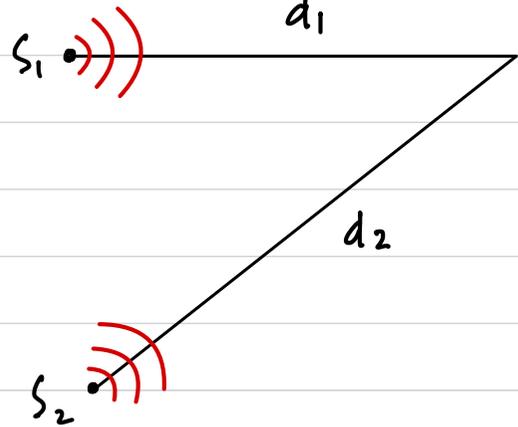
PHYSICS BY
Kashan Rashid

Intermediate Interference



PHYSICS BY
Kashan Rashid

Path Difference

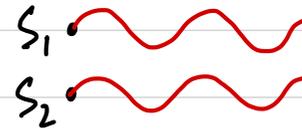


$$\text{path diff} = |d_2 - d_1|$$

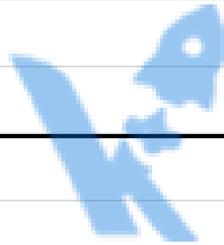
$$\text{path diff} = n\lambda$$

λ : wavelength
 n : no. of waves

If the sources are vibrating
in phase



$n = 0, 1, 2, 3, \dots$ Constructive Interference
 $n = 0.5, 1.5, 2.5, \dots$ Destructive Interference

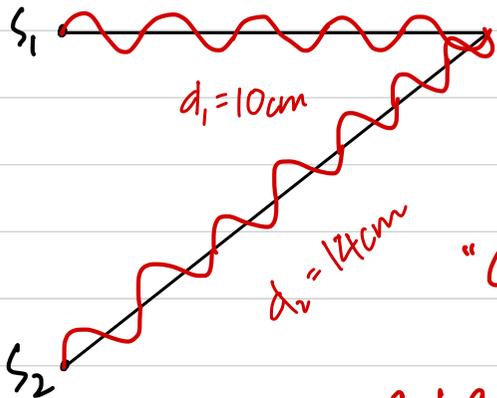


PHYSICS BY

Kashan Rashid

Example #1

$$\lambda = 2\text{cm} \quad d_1 = 10\text{cm} \quad d_2 = 14\text{cm}$$



$$\text{path diff} = n\lambda$$
$$14 - 10 = n(2)$$

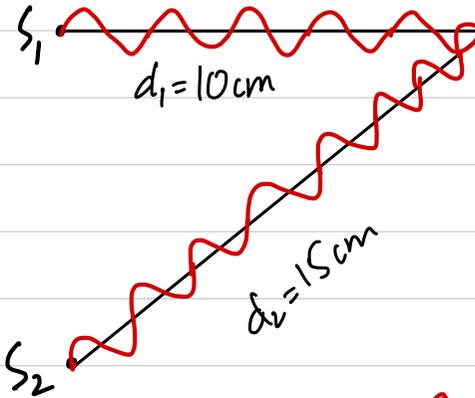
$$n = 2$$

"Constructive
Interference"

$$a + a = 2a \quad (a: \text{amplitude})$$

Example #2

$$\lambda = 2\text{cm} \quad d_1 = 10\text{cm} \quad d_2 = 15\text{cm}$$



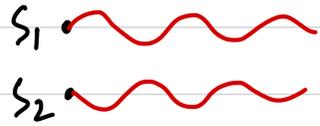
$$\text{path diff} = n\lambda$$
$$15 - 10 = n(2)$$

$$n = 2.5$$

"Destructive
Interference"

$$a - a = 0$$

If the sources vibrate out of phase



"RULES FLIP"

Path diff = $n\lambda$

If $n = 0, 1, 2, 3, \dots$ Destructive Interference

If $n = 0.5, 1.5, 2.5, \dots$ Constructive Interference

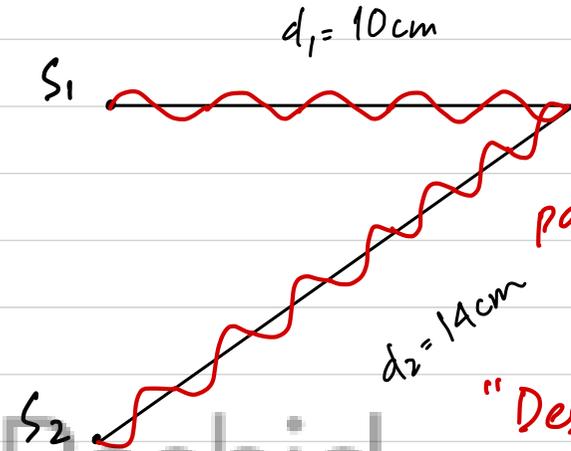


PHYSICS BY

Kashan Rashid

Example #3

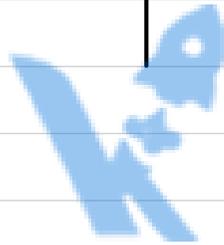
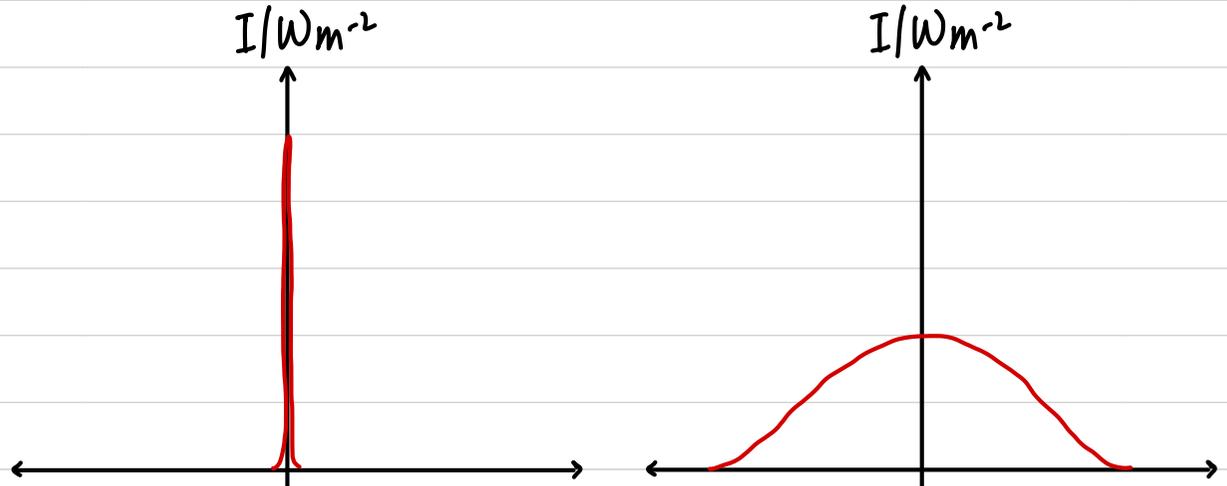
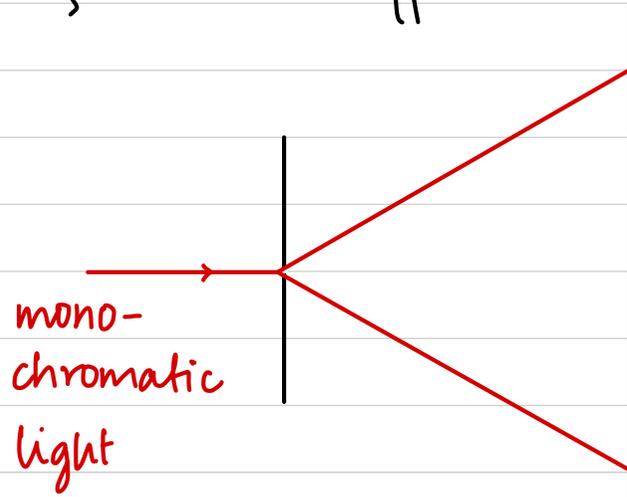
$\lambda = 2\text{cm}$ $d_1 = 10\text{cm}$ $d_2 = 14\text{cm}$
(Sources vibrate out of phase)



path diff = $n\lambda$
 $14 - 10 = n(2)$
 $n = 2$

"Destructive Interference"

Single Slit Diffraction



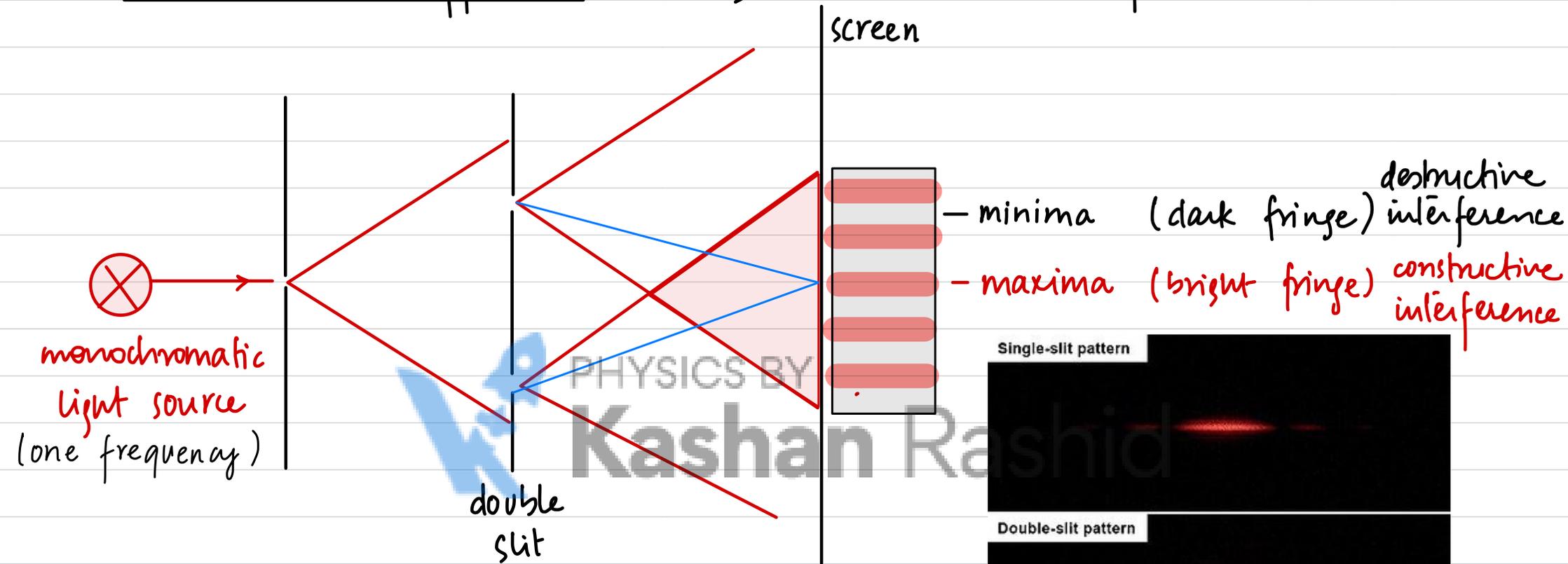
PHYSICS BY
Kashan Rashid

NO SLIT



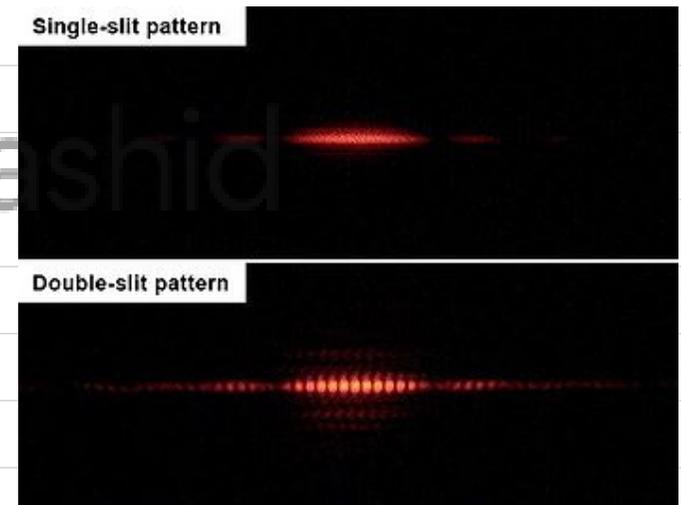
SINGLE SLIT
Intensity falls as light spreads on a larger area.

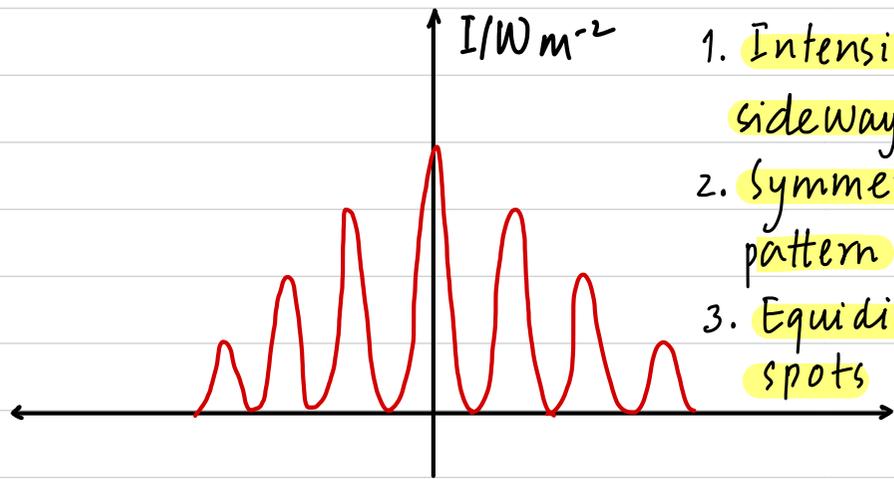
2. Double Slit Diffraction (Young's Double Slit Experiment)



Why is this pattern produced??

- light coming from two slits meet at different points on screen.
- At some points light rays are in phase so a bright spot is seen.
- At some points light rays are out of phase so a dark region is seen.





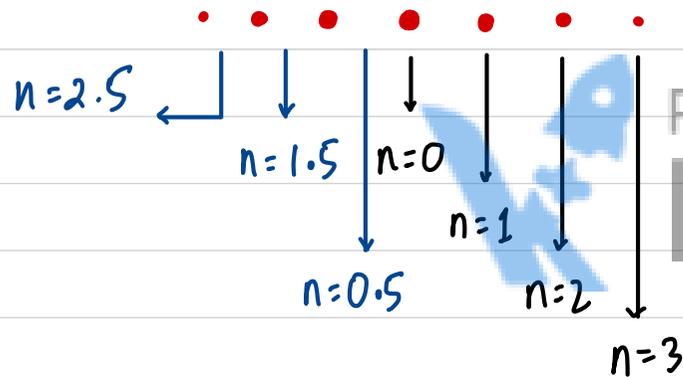
1. Intensity fell sideways
2. Symmetric pattern
3. Equidistant spots

Dark spot

- Destructive interference
- path diff = $n\lambda$ where $n = 0.5, 1.5, 2.5, \dots$
- phase diff = 180°

Formula:

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



PHYSICS BY

Kashan Rashid

Bright spot

- constructive interference
- path diff = $n\lambda$ where $n = 0, 1, 2, 3, \dots$
- phase diff = 0°

a : slit separation

λ : wavelength

x : fringe separation

D : slit-to-screen distance

Note: Bright spots are equidistant from one another.

Effects on Fringe pattern

1. Wavelength of light increased (frequency decreased, blue color to red)
fringe separation: **increase** ($x \propto \lambda$)

brightness of bright fringe: **unchanged**

darkness of dark fringe: **unchanged**

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

2. Slit to screen distance increased

fringe separation: **increase** ($x \propto D$)

brightness of bright fringe: **decrease** (spot becomes large)

darkness of dark fringe: **unchanged**

3. Slit separation increased

fringe separation: **decrease** ($x \propto \frac{1}{a}$)

brightness of bright fringe: **unchanged**

darkness of dark fringe: **unchanged**

4. Intensity of light decreased (lamp dim, smaller slit size, lamp far away from the slits)

fringe separation: *unchanged*

brightness of bright fringe: *decrease*

darkness of dark fringe: *unchanged*

5. Light coming from one of the two slits is decreased

fringe separation: *unchanged*

brightness of bright fringe: *decrease (less overall light is reduced)*

darkness of dark fringe: *decrease (less dark as no pure destructive interference)*

Diffraction Grating

Problems with double slit

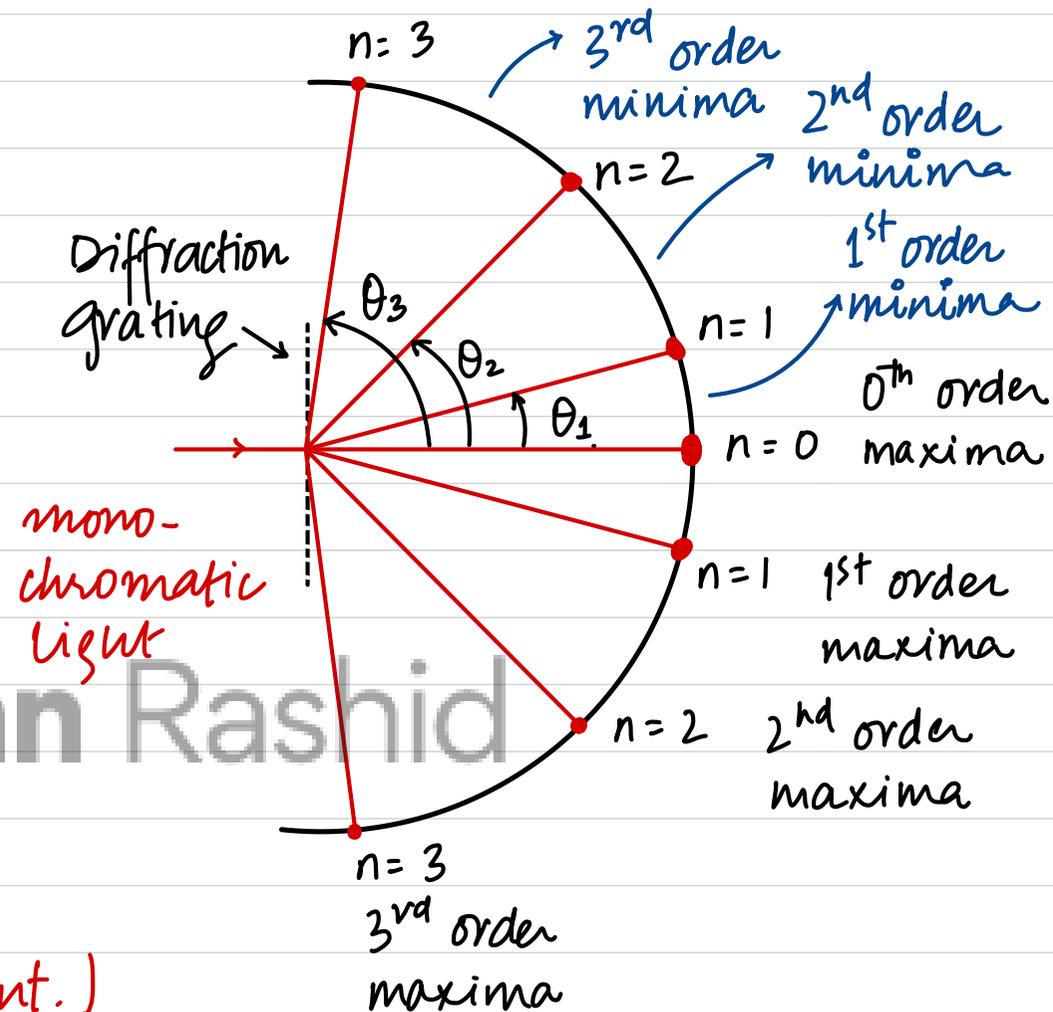
1. Very low intensity of spots
2. Very small gap between spots

Diffraction grating resolved the problems.

Grating comprises of hundreds of slits per cm so that more light can pass and bright spots are produced on screen.

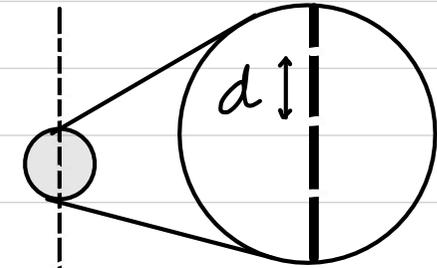
Maxima : Bright fringe (Constructive Int.)

Minima : Dark fringe (Destructive Int.)



$$n \lambda = d \sin \theta \rightarrow \text{angle between } 0^{\text{th}} \text{ and } n^{\text{th}} \text{ order}$$

n → order of maxima
 λ → wavelength
 d → slit separation (length of 1 line)



closer

2 Monochromatic light is incident normally on a diffraction grating having 4000 lines per centimetre. The angular separation of the zeroth- and first ^{$n=1$} -order maxima is found to be 10° .

a) Calculate the wavelength of the incident light.

Calculations for finding d

4000 lines — 0.01 m

1 line — d

$$d = \frac{0.01}{4000} = 2.5 \times 10^{-6} \text{ m}$$

a) $n \lambda = d \sin \theta$
 (1) $\lambda = 2.5 \times 10^{-6} \sin 10^\circ$
 $\lambda = 4.34 \times 10^{-7} \text{ m}$
 (434 nm) "Blue"

b) angle of 3rd order maxima
 $n \lambda = d \sin \theta$
 (3) $(4.34 \times 10^{-7}) = 2.5 \times 10^{-6} \sin \theta$
 $\theta = 31.4^\circ$

VIBGYOR

400nm

700nm

c) angle between 1st and 3rd order maxima

$$\begin{aligned}\theta_{1 \rightarrow 3} &= \theta_3 - \theta_1 \\ &= 31.4^\circ - 10^\circ \\ &= 21.4^\circ\end{aligned}$$

d) angle between both 3rd order maxima

$$\begin{aligned}\theta_{3 \rightarrow 3} &= 31.4^\circ \times 2 \\ \theta_{3 \rightarrow 3} &= 62.8^\circ\end{aligned}$$

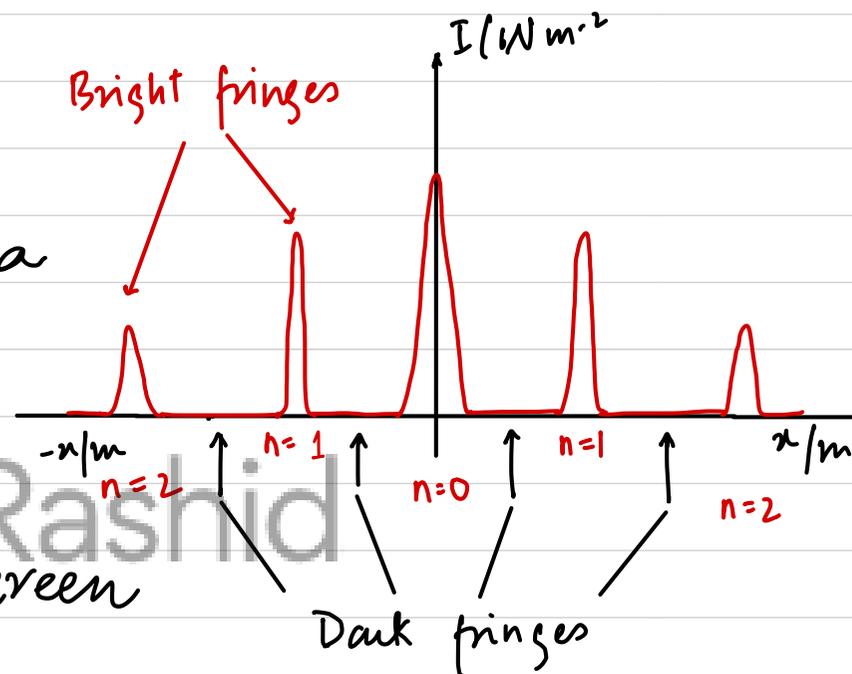
e) highest order maxima visible on screen

$$\theta_{\max} = 90^\circ$$

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

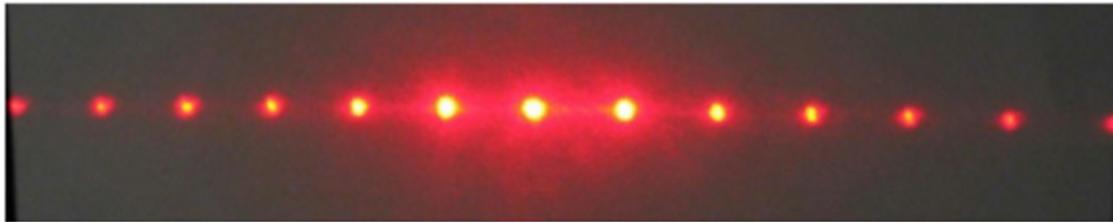
$$n(4.34 \times 10^{-7}) = 2.5 \times 10^{-6} \sin 90^\circ$$

$$n = 5.76 \quad \text{so} \quad \boxed{n = 5}$$

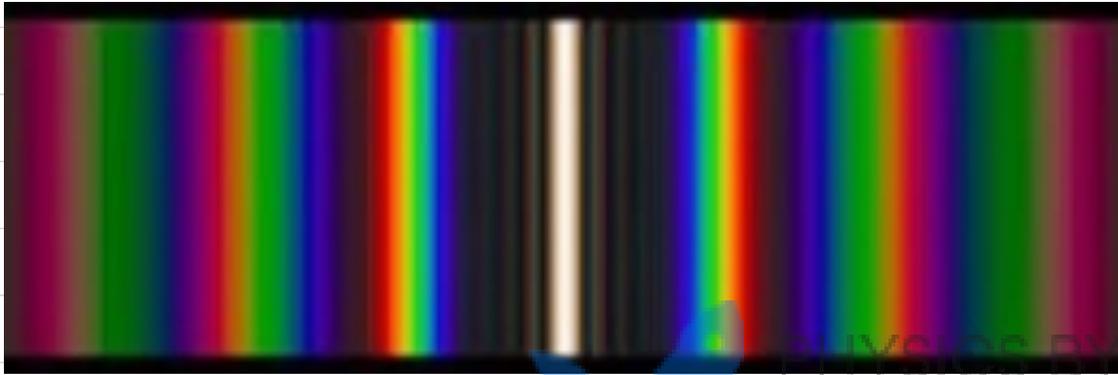


f) total bright spots on screen

$$5 + 5 + 1(\text{zeroth order}) = 11 \text{ bright fringes!}$$



Diffraction of Red Light



When white light is passed through a diffraction grating.

- White light comprises of colors from red to blue
- Every color has its own wavelength.
- Upon diffraction, colors spread based on their wavelengths.

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

$$\uparrow \lambda \propto \sin \theta \uparrow$$

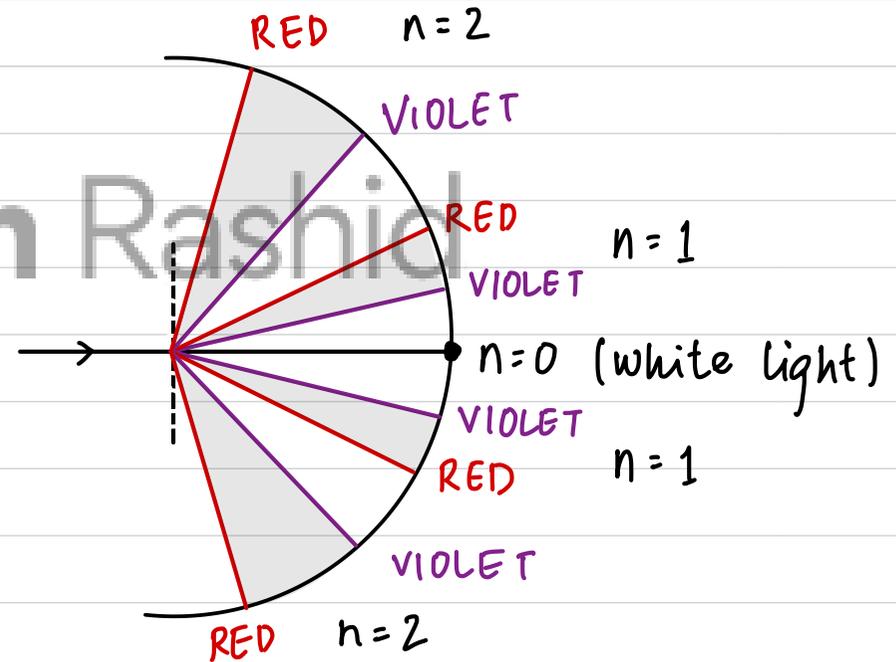
more λ



more diff.



more θ



$n=0$ is white spot as every color has a constructive interference over there. Path diff = 0 & phase diff = 0° colors combine to form white light

Kashan Rashid

(390nm) V I B G Y O R (650nm)
 low wavelength → high wavelength

MJ / 2015 / P13

29 Wave generators at points X and Y produce water waves of the same wavelength. At point Z, the waves from X have the same amplitude as the waves from Y. Distances XZ and YZ are as shown.

path difference = $n\lambda$

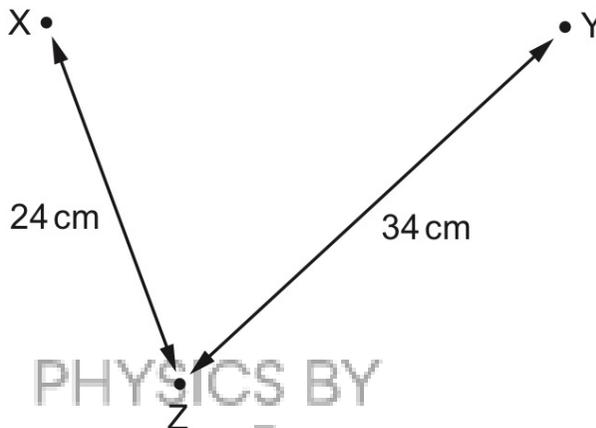
$$34 - 24 = n\lambda$$

$$10 = n\lambda$$

if $\lambda = 2$ $n = 5$

if $\lambda = 3$ $n = 3.33$

if $\lambda = 4$ $n = 2.5$



PHYSICS BY
Kashan Rashid

When the wave generators operate in phase, the amplitude of oscillation at Z is zero.

What could be the wavelength of the waves?

A 2 cm

B 3 cm

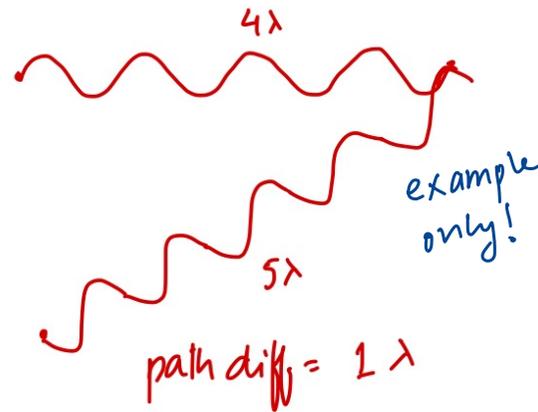
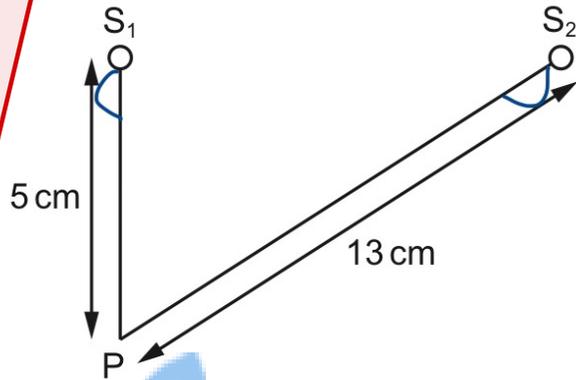
C 4 cm

D 6 cm

26 The diagram shows two sources of waves S_1 and S_2 . The sources oscillate with a phase difference of 180° . ✓

path diff = $n\lambda$
 $n = 0, 1, 2, 3 \dots$ destructive
 $n = 0.5, 1.5, 2.5, \dots$ const

If source oscillates out of phase!



The sources each generate a wave of wavelength 2.0 cm. Each source produces a wave that has amplitude x_0 when it reaches point P .

What is the amplitude of the oscillation at P ?

$path\ diff = n\lambda$
 $(13 - 5) = n(2)$
 $n = 4$ so destructive interference

A 0

B $\frac{x_0}{2}$

C x_0

D $2x_0$

• If the sources are operating out of phase, one would make crest and the other would make trough at the same time so the rules of path difference now **FLIP!**

- 5 Two sources S_1 and S_2 of sound are situated 80 cm apart in air, as shown in Fig. 5.1.

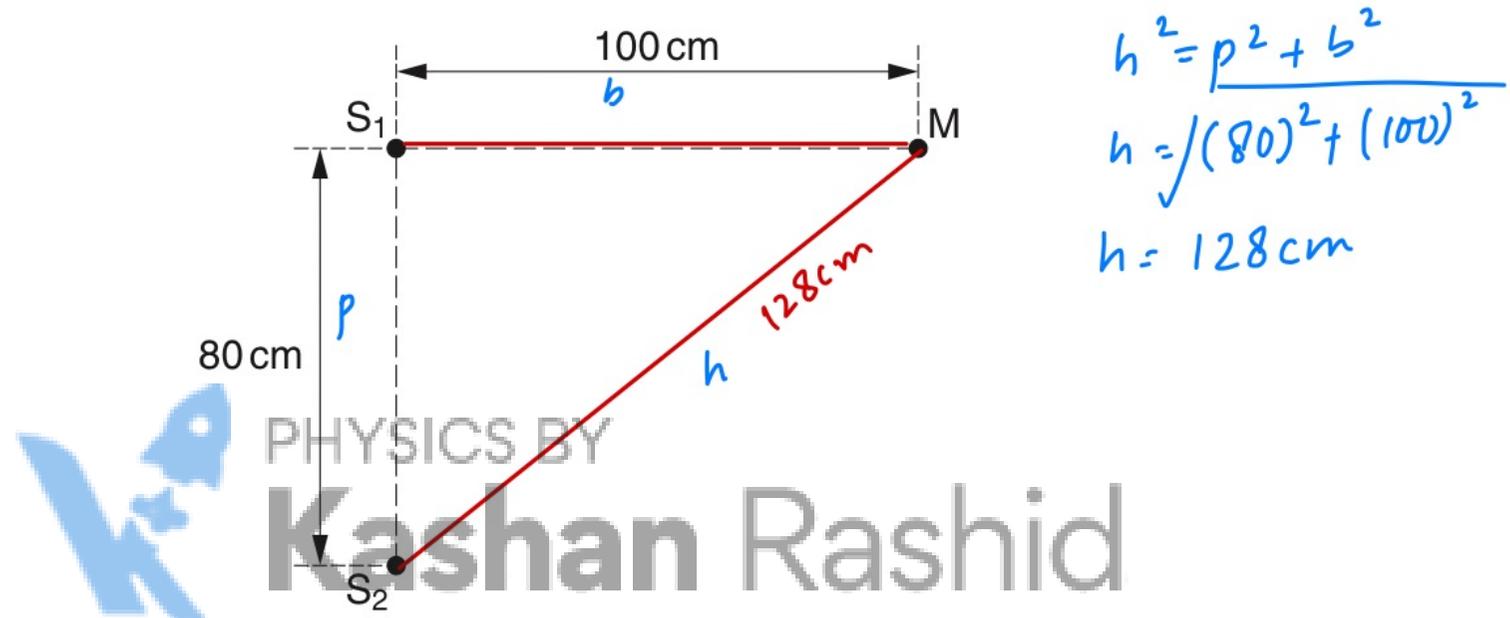


Fig. 5.1

The frequency of vibration can be varied. The two sources always vibrate in phase but have different amplitudes of vibration.

A microphone M is situated a distance 100 cm from S_1 along a line that is normal to S_1S_2 .

As the frequency of S_1 and S_2 is gradually increased, the microphone M detects maxima and minima of intensity of sound.

(a) State the two conditions that must be satisfied for the intensity of sound at M to be zero.

1. The phase difference between interfering waves must be $180^\circ / \pi$ rad.

2. Waves must have the same amplitude.

3. Path difference between waves = $n\lambda$ where $n = 0.5, 1.5, 2.5, \dots$

[2]

(b) The speed of sound in air is 330 ms^{-1} .

The frequency of the sound from S_1 and S_2 is increased. Determine the number of minima that will be detected at M as the frequency is increased from 1.0 kHz to 4.0 kHz .

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

$$\text{path diff} = n\lambda$$

$$\text{path diff} = \frac{nv}{f}$$

$$0.28 = \frac{nv}{f}$$

if $n = 0.5$

$$0.28 = \frac{(0.5)(330)}{f}$$

$$f = 589 \text{ Hz}$$

if $n = 1.5$

$$0.28 = \frac{(1.5)(330)}{f}$$

$$f = 1767 \text{ Hz}$$

if $n = 2.5$

$$f = 2946 \text{ Hz}$$

if $n = 3.5$

$$f = 4125 \text{ Hz}$$

2

number = [4]

M/J /2008/P1

29 Light of wavelength 700 nm is incident on a pair of slits, forming fringes 3.0 mm apart on a screen.

What is the fringe spacing when light of wavelength 350 nm is used and the slit separation is doubled? WAVES 2008

- A 0.75 mm B 1.5 mm C 3.0 mm D 6.0 mm

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

$\lambda = 700 \text{ nm}$ $\lambda = 350 \text{ nm}$

$x = 3.0 \text{ mm}$ $x = ?$ $x \propto \lambda$ $x \propto \frac{1}{a}$

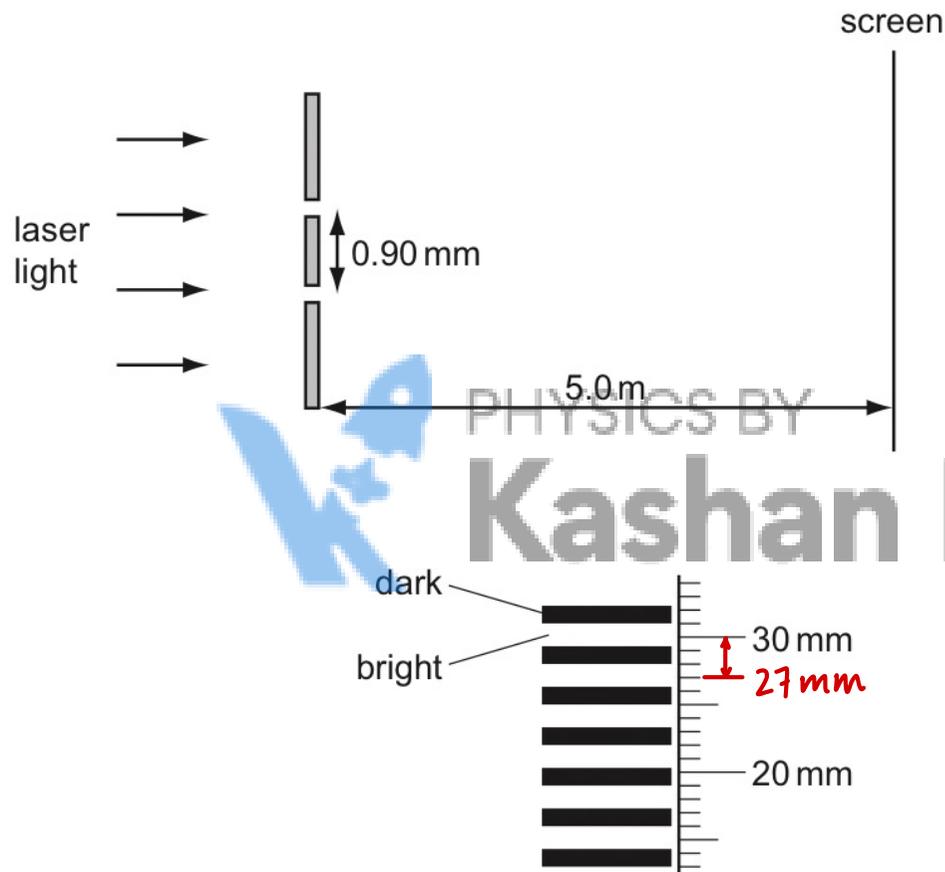
a $2a$

$x_n = \frac{x}{2 \times 2}$ so $x_n = \frac{3}{4}$

$\lambda \nearrow$ $\nwarrow a$ $x_n = 0.75 \text{ mm}$

PHYSICS BY
Kashan Rashid

- 29 The diagrams show the arrangement of apparatus for a Young's slits experiment and also part of the pattern formed on the screen with a ruler placed next to it.



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

$$x = 30 - 27$$

$$x = 3 \text{ mm}$$

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

$$3 \times 10^{-3} = \frac{\lambda (5)}{0.9 \times 10^{-3}}$$

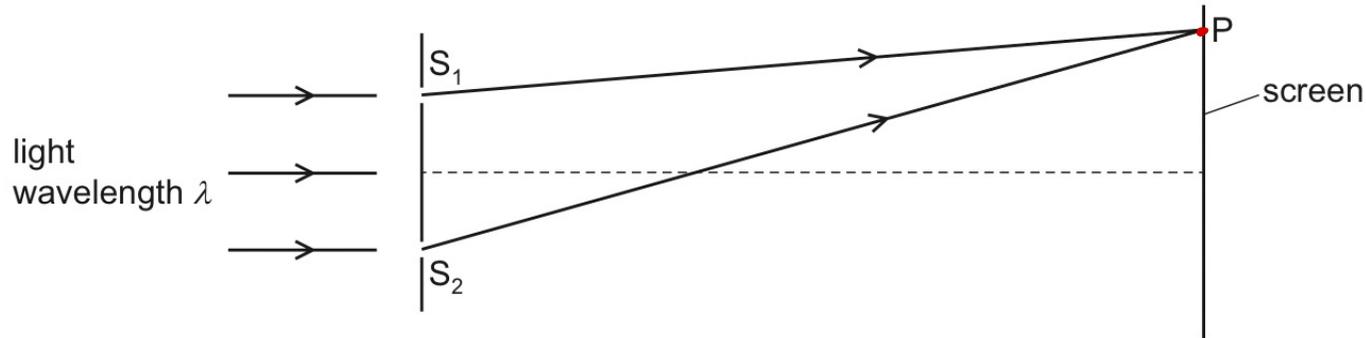
$$\lambda = 5.4 \times 10^{-7} \text{ m}$$

What is the wavelength of the light?

- A $4.8 \times 10^{-7} \text{ m}$ **B** $5.4 \times 10^{-7} \text{ m}$ C $3.2 \times 10^{-6} \text{ m}$ D $3.4 \times 10^{-6} \text{ m}$

MJ/2017/P13

- 28 Monochromatic light of wavelength λ is incident on two narrow slits S_1 and S_2 , a small distance apart. A series of bright and dark fringes are observed on a screen a long distance away from the slits.



The n th dark fringe from the central bright fringe is observed at point P on the screen.

Which equation is correct for all positive values of n ?

A $S_2P - S_1P = \frac{n\lambda}{2}$

B $S_2P - S_1P = n\lambda$

C $S_2P - S_1P = (n - \frac{1}{2})\lambda$ ✓

D $S_2P - S_1P = (n + \frac{1}{2})\lambda$

path diff = $n\lambda$

0.5, 1.5, 2.5

$n=1$

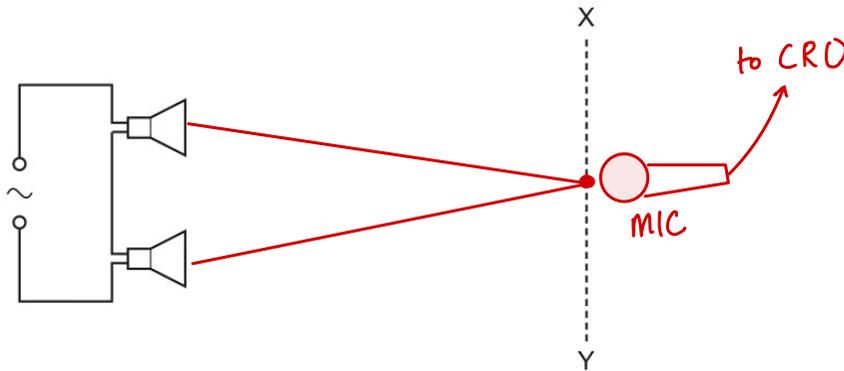
path diff = $(1 - \frac{1}{2})\lambda$ 0.5λ

$n=2$

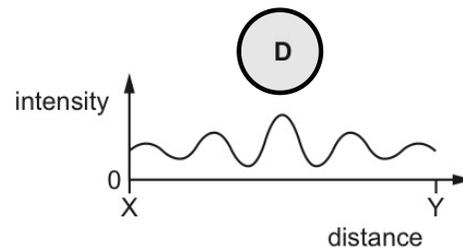
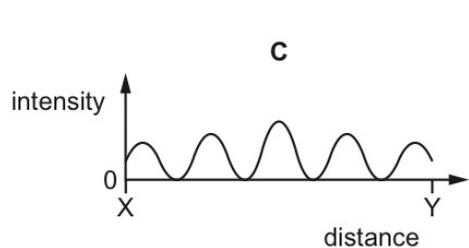
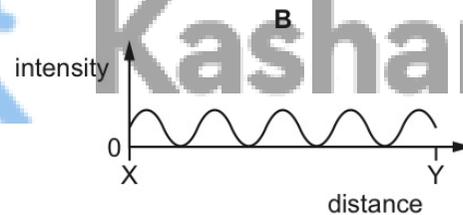
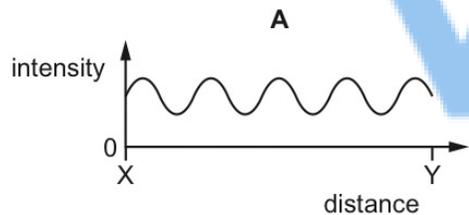
path diff = $(2 - \frac{1}{2})\lambda$ 1.5λ

Double Slit Experiment with Sound.

26 Two identical loudspeakers are connected in series to an a.c. supply, as shown.



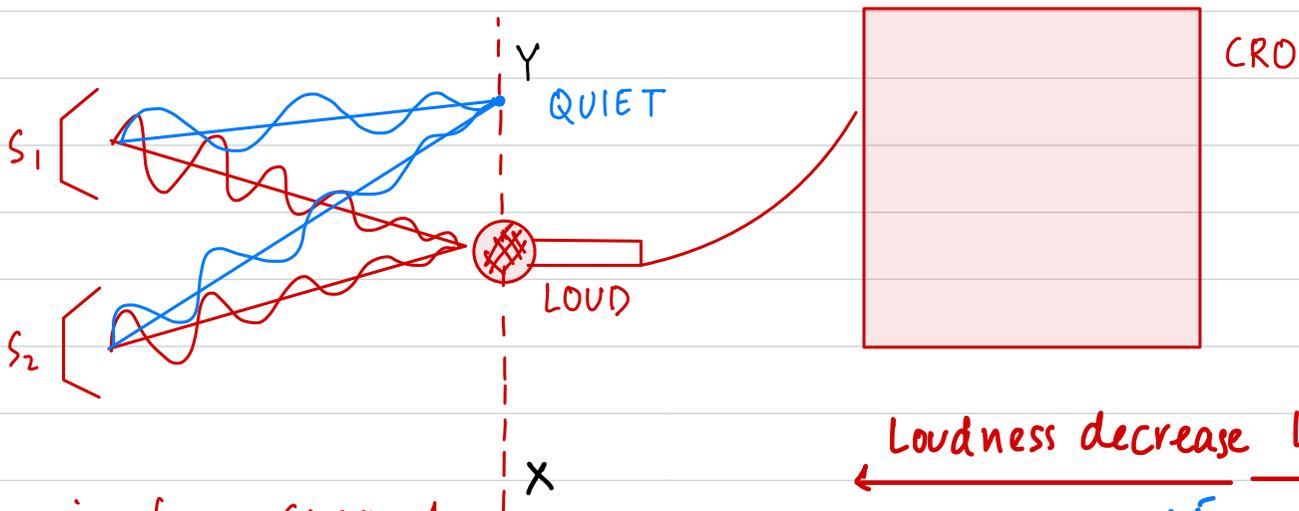
Which graph best shows the variation of the intensity of the sound with distance along the line XY?



For an interference pattern to be produced, the waves must be coherent i.e. they must have a constant phase difference.

• In order to have a constant phase difference
→ One light source and two slits were used so that light from both slits have the same phase difference.

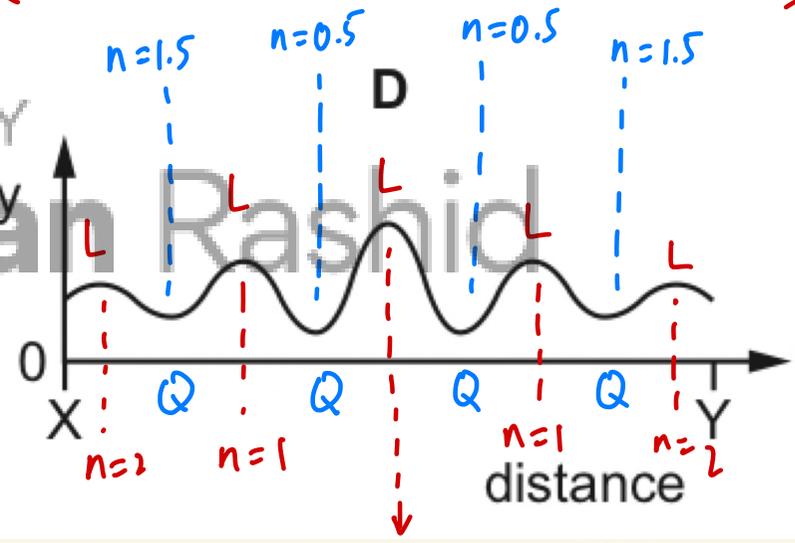
→ Two loudspeakers and one power source is used so that both speakers produce coherent waves.



- Sound coming from source 1 travels less distance than source 2. Hence wave from S_2 has a smaller amplitude than wave from S_1 .
- At Y , no pure destructive interference occurs and some intensity is still left.

PHYSICS BY
intensity
Kashan Rashid

Loudness decrease Loudness decrease



middle
constructive
interference
 $n=0$

- 5 (a) State three conditions required for maxima to be formed in an interference pattern produced by two sources of microwaves.

1. Phase diff = 0 or in phase
2. Path diff = $n\lambda$ where $n = 0, 1, 2, 3 \dots$ with the sources oscillating in phase
3. Waves must meet at a point.

[3]

- (b) A microwave source M emits microwaves of frequency 12 GHz. Show that the wavelength of the microwaves is 0.025 m.

$$v = f\lambda$$

$$3 \times 10^8 = (12 \times 10^9) \lambda$$

$$\lambda = 0.025 \text{ m}$$



PHYSICS BY
Kashan Rashid

11

- (c) Two slits S_1 and S_2 are placed in front of the microwave source M described in (b), as shown in Fig 5.1.

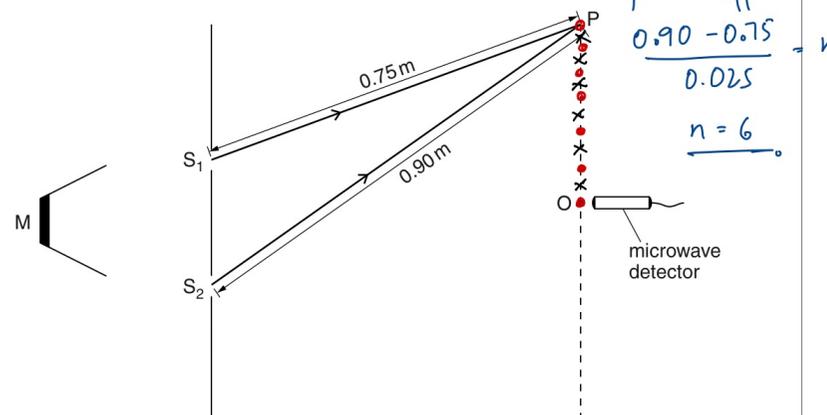


Fig. 5.1 (not to scale)

The distances S_1O and S_2O are equal. A microwave detector is moved from O to P. The distance S_1P is 0.75 m and the distance S_2P is 0.90 m.

9702/21/M/J/13

The microwave detector gives a maximum reading at O.

State the variation in the readings on the microwave detector as it is moved slowly along the line from O to P.

The reading on the detector increases and decreases periodically. Including the maxima at O, 7 maxima are detected and six minima are detected. Intensity of maxima's decrease from O to P.

[3]

- (d) The microwave source M is replaced by a source of coherent light.

State two changes that must be made to the slits in Fig. 5.1 in order to observe an interference pattern.

1. Decrease the size of slit to the size of wavelength of light
2. Decrease the gap between the slits.

[2]

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

For
Examiner's
Use

For
Examiner's
Use

6 (a) Two overlapping waves of the same type travel in the same direction. The variation with distance x of the displacement y of each wave is shown in Fig. 6.1.

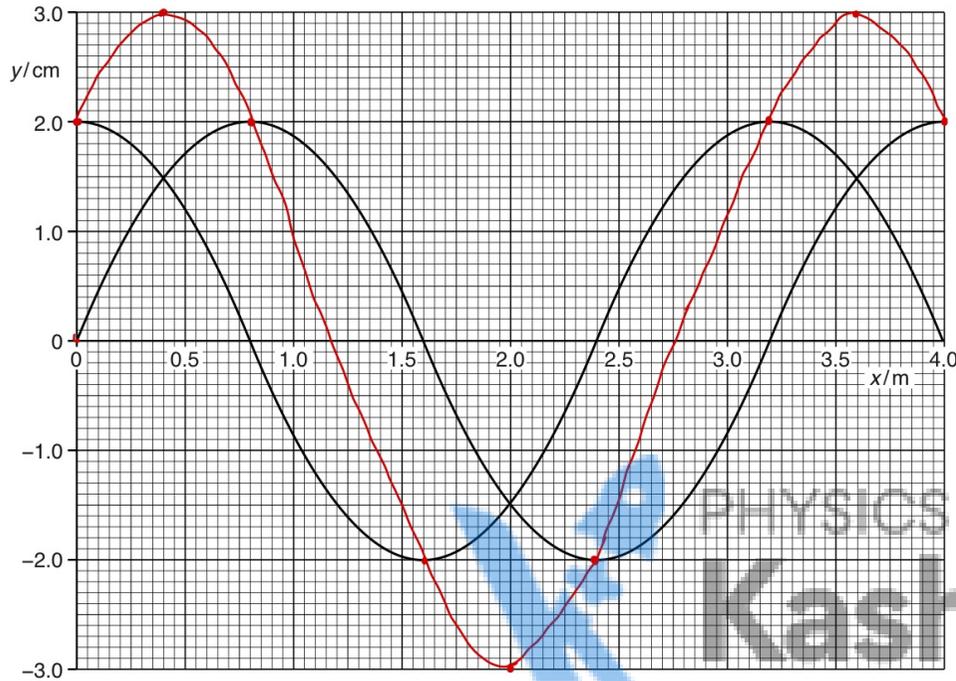


Fig. 6.1

(iii) State the phase difference between the waves.

phase difference = 90° [1]

(iv) Use the principle of superposition to sketch, on Fig. 6.1, the resultant wave. [2]

(b) An interference pattern is produced with the arrangement shown in Fig. 6.2.

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

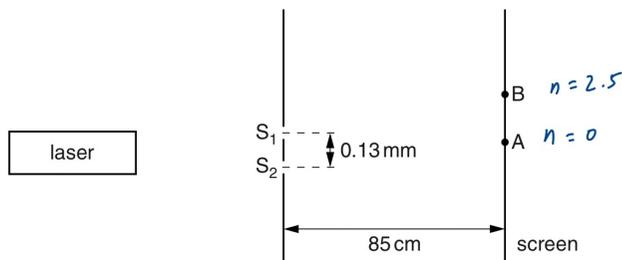


Fig. 6.2 (not to scale)

The speed of the waves is 240 m s^{-1} . The waves are coherent and produce an interference pattern.

(i) Explain the meaning of coherence and interference.

coherence: The waves have a constant phase difference throughout their motion.

interference: When two waves meet at a point, they produce a new wave which is the resultant of both. [2]

(ii) Use Fig. 6.1 to determine the frequency of the waves.

$$v = f\lambda$$

$$240 = f(3.2)$$

$$f = 75 \text{ Hz}$$

frequency = 75 Hz [2]

© UCLES 2015

9702/23/M/J/15

Laser light of wavelength λ of 546 nm is incident on the slits S_1 and S_2 . The slits are a distance 0.13 mm apart. The distance between the slits and the screen is 85 cm.

Two points on the screen are labelled A and B. The path difference between S_1A and S_2A is zero. The path difference between S_1B and S_2B is 2.5λ . Maxima and minima of intensity of light are produced on the screen.

(i) Calculate the distance AB.

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

$$\lambda = \frac{546 \times 10^{-9} \times (85 \div 100)}{0.13 \div 1000}$$

$$\lambda = 3.57 \times 10^{-3}$$

$AB = 2.5 (3.57 \times 10^{-3}) = 8.925 \times 10^{-3}$

distance = 8.93×10^{-3} m [3]

(ii) The laser is replaced by a laser emitting blue light. State and explain the change in the distance between the maxima observed on the screen.

Blue has a shorter wavelength than 546 nm. Hence the fringe separation will decrease as $\lambda \propto x$. [1]