Learning CORNER

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

TOPIC *opening ....*

Question 1

A student sets up the apparatus illustrated in Fig. 3.1 in order to observe two-source interference fringes.

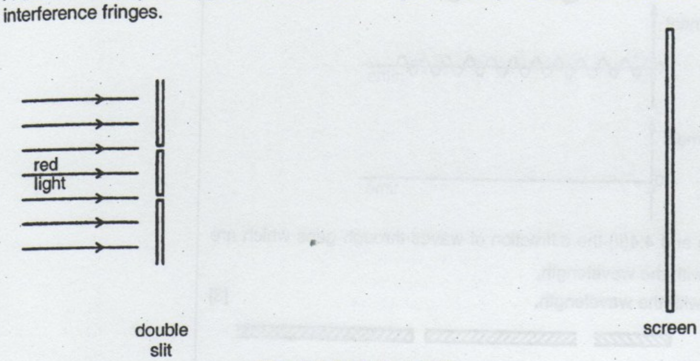

Fig. 3.1 (not to scale)

(a) State a suitable separation for the two slits in the double slit. [1]

(b) State and explain what change, if any, occurs in the separation of the fringes and in the contrast between bright and dark fringes observed on the screen, when each of the following changes is made separately.

(i) increasing the intensity of the red light incident on the double slit [3]

(ii) increasing the distance between the double slit and the screen [4]

(iii) reducing the intensity of light incident on one slit of the double slit [3]

[D99/P2/Q3]

Suggested Solution:

(a) 0.50 mm

(b) (i) No change in the separation of the fringes is observed because it depends on the wavelength of the light incident on the double slit, the distance between the double slit and the screen and the separation between the double slit and not on the intensity of the light.

The contrast between bright and dark fringes observed on the screen will increase when the intensity of the light is increased. This is because the intensity of the bright fringes increase due to the constructive interference of the two coherent sources of greater intensity.

(ii) Increasing the distance between the double slit and the screen would increase the separation of the fringes because it is directly proportional to the distance between the double slit and the screen.

The contrast between bright and dark fringes observed on the screen would decrease. The intensity of light varies inversely with the square of the distance from the source. The fringes observed when the distance between the double slit and the screen is increased would be due to the interference of two wavelengths of lower intensity.

(iii) Reducing the intensity of light incident on one slit of the double slit has no effect on the separation of the fringes. The contrast between bright and dark fringes observed on the screen would decrease.

(a) The usual slit separation is in the region of a fraction of a millimeter in order for the interference fringes to be clearly visible. To check whether the answer is plausible, the formula for separation between successive fringes:

$$y = \frac{\lambda D}{d}$$

$$= \frac{(7 \times 10^{-7})(1.5)}{0.50 \times 10^{-3}}$$

$$= 2.1 \text{ mm}$$

The value of 1.5 m is chosen as the distance between the slits and the screen as this distance is of this order of magnitude. Any answer for (a) is acceptable as long as it is in the order of a fraction of a millimeter. Give answers to one or two significant figures.

(b) (i) Remember that the intensity is proportional to the square of the amplitude of a wave. Increasing the intensity of the incident light increases the amplitude of the two coherent sources from the double slits. Where there is positive interference, the resulting wave has a larger amplitude and hence a greater intensity compared to before the increase. Similarly reasoning is used for the parts in (b)(ii) and (b)(iii) pertaining to the contrast of the fringes.

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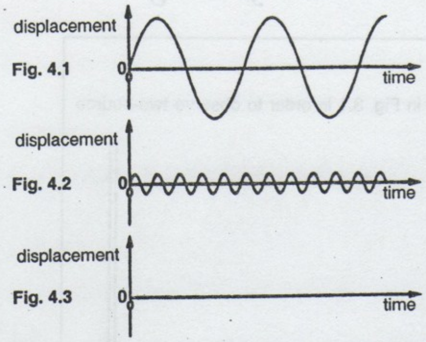
Question 2

(a) Two waves of different frequency pass through the same point. Figs. 4.1 and 4.2 show the displacement-time graphs for the waves. On Fig. 4.3, sketch the resultant displacement showing the superposition of these two waves. [2]



(b) Sketch on Figs. 4.4(i) and 4.4(ii) the diffraction of waves through gaps which are

(i) large compared with the wavelength,

(ii) small compared with the wavelength. [3]

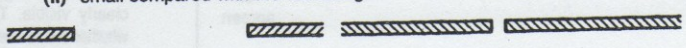


Fig. 4.4.(i) Fig. 4.4(ii)

(c) Two microwave sources A and B are in phase with one another. They emit waves of equal amplitude and of wavelength 30.0 mm. They are placed 140 mm apart and at a distance of 810 mm from a line OP along which a detector is moved, as shown in Fig. 4.5.

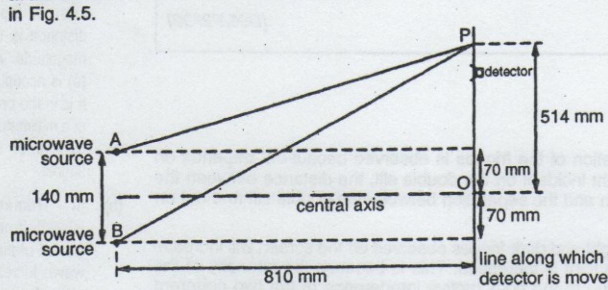


Fig. 4.5 (not to scale)

(i) Using Pythagoras' theorem, it can be shown that the distance AP is 923.7 mm. Calculate the number of wavelengths between source A and point P. [1]

(ii) Show that there are 33.3 wavelengths between source B and point P. [2]

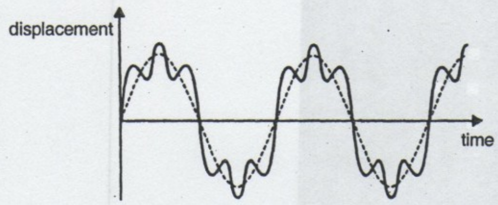
(iii) 1. State what intensity of microwaves will be received by the detector when it is at P.

2. Describe how the intensity of reception varies as the detector is moved from P to the point O on the central axis. [3]

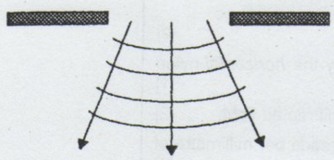
[J00/P2/Q4]

Suggested Solution:

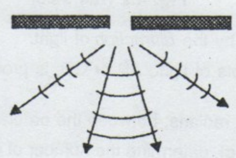
(a)



(b) (i)



(ii)



(c) (i) number of wavelengths between A and P $= \frac{\text{distance AP}}{\text{wavelength}} = \frac{923.7 \text{ mm}}{30.0 \text{ mm}} = 30.8$

(ii) number of wavelengths between B and P $= \frac{\text{distance BP}}{\text{wavelength}} = \frac{\sqrt{810^2 + (514+70)^2}}{30}$

$= 33.3$ **(shown)**

(iii) 1. minimum intensity.

2. As the detector is moved from P to O on the central axis, the intensity of reception varies from minimum at P (path difference of $\frac{5\lambda}{2}$) to maximum at O (path difference of 0). Between P and O, there are two other minima (corresponding to path differences of $\frac{3\lambda}{2}$ and $\frac{\lambda}{2}$)and two other maxima (corresponding to path differences of 2λ and λ).

Learning CORNER

(a) The resultant displacement is the algebraic sum of the displacements of the two waves.

(b) (i) There is less diffraction of the waves where the gap is large compared with the wavelength.

(ii) There is more diffraction of the waves where the gap is small compared with the wavelength.

(c) (ii) Use Pythagoras' theorem to calculate distance BP.

(iii) 1. Path difference at P

$= BP - AP$

$= (33.3 - 30.8)\lambda$

$= 2.5\lambda$

$= 5\left(\frac{\lambda}{2}\right)$

where λ is the wavelength of the microwave. Since there is an odd number of $\frac{\lambda}{2}$ in the path difference, the intensity at point P will be at the minimum.

2. Minima occur where the path difference equals an odd number of $\frac{\lambda}{2}$.

Maxima occur where the path difference equals an even number of $\frac{\lambda}{2}$.

Question 3

Light from a distant source of monochromatic light of wavelength 590 nm passes through a fine nylon mesh. The light is then incident on a screen, as illustrated in Fig. 4.1.

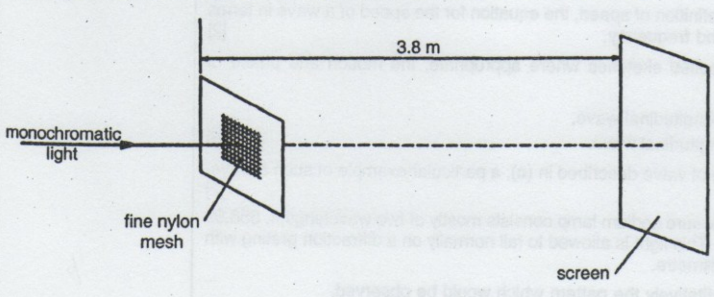


Fig. 4.1

The threads of the nylon mesh act as a diffraction grating with lines in the horizontal and in the vertical direction. Part of the pattern of spots of light on the screen is shown in Fig. 4.2

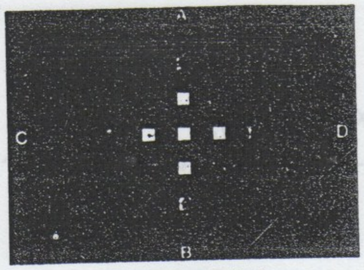


Fig. 4.2 (full size)

(a) Explain what is meant by the *diffraction* of light. [2]

(b) State which line of spots of light, AB or CD, is produced by the *horizontal* nylon threads. [1]

(c) Calculate the angle, in radians, between the orders of the diffracted light. [2]

(d) Using your answer to **(c)**, determine the number of nylon threads per millimetre of the mesh. [4]

[D00/P2/Q4]

Suggested Solution:

(a) The *diffraction* of light refers to the spreading of light when it passes through apertures or around obstacles.

(b) AB

(c) Distance between the zeroth order and the fourth order maxima (near D) = 3.2 cm

$\Rightarrow$ Distance between consecutive maxima = 3.2 ÷ 4 = 0.8 cm

$$\text{Angle between the orders} = \frac{\text{distance between consecutive orders}}{\text{distance between nylon mesh and screen}}$$

$$= \frac{0.8 \times 10^{-2}}{3.8} = 2.1 \times 10^{-3} \text{ rad}$$

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

$$\Rightarrow a = \frac{n\lambda}{\sin\theta} = \frac{1 \times 590 \times 10^{-9}}{\sin(2.1 \times 10^{-3})} = 2.81 \times 10^{-4} \text{ m}$$

(b) The horizontal nylon threads would cause the light to spread or diffract vertically. The vertical nylon threads would cause the light to diffract horizontally.

(c) Notice that Fig. 4.2 is full size. This indicates that you can obtain information on unknown variable through direct measurement from Fig.4.2.

Question 4

(a) State the meaning of *wavelength* and *frequency* as applied to wave motion. [2]

(b) Deduce, from the definition of speed, the equation for the speed of a wave in terms of its wavelength and frequency. [2]

(c) Describe, using labelled sketches where appropriate, the motion and phase of particles in

(i) a progressive longitudinal wave,

(ii) a stationary longitudinal wave. [6]

(d) State, for each type of wave described in **(c)**, a particular example of such a wave. [2]

(e) Light from a low pressure sodium lamp consists mostly of two wavelengths, 588.99 nm and 589.59 nm. This light is allowed to fall normally on a diffraction grating with 500.00 lines per millimetre.

(i) Describe quantitatively the pattern which would be observed.

(ii) Calculate the maximum angular separation between the light of the two wavelengths.

(iii) What problem would be likely to arise in observing the spectral lines in the order in (ii)? [8]

[D00/P3/Q3]

Suggested Solution:

(a) *Wavelength* refers to the distance between corresponding points in successive waveforms, such as two successive crests or two successive troughs.
Frequency refers to the number of oscillations completed per unit time.

(b) $\text{Speed} = \dfrac{\text{Distance travelled}}{\text{Time taken}}$

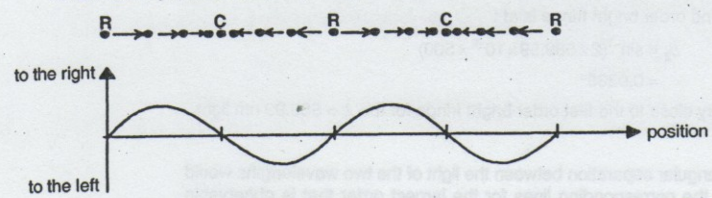
For a complete cycle,

Distance travelled by a waveform = Wavelength

$\text{Time taken} = \text{Period} = \dfrac{1}{\text{Frequency}}$

$\therefore \quad \text{Speed} = \dfrac{\text{Distance travelled}}{\text{Time taken}} = \dfrac{\text{Wavelength}}{1/\text{Frequency}} = \text{Wavelength} \times \text{Frequency}$

(c) (i) In a longitudinal wave, the particles vibrate in the same direction as the direction of travel of the wave, giving rise to regions of high density (compressions C) and of low density (rarefactions R) along the wave.



The row of dots in the sketch above show the actual positions of the particles in the medium in which the progressive longitudinal wave is travelling, at a particular point in time.

The arrows represent the displacements of the particles from their equilibrium positions. The graph shows the variation of the displacement of each particle with its position along the wave.

In a progressive longitudinal wave

1. the regions of C and R travel at the speed of the wave.
2. each particle vibrates about its mean position with the same amplitude and frequency.
3. the regions of maximum compression are 90° phase ahead of the greatest displacement in the direction of the wave.
4. adjacent particles are not in phase with one another. However, particles that are integral multiples of wavelengths apart are in phase with one another.

(ii) In a stationary longitudinal wave:

1. there are points where the displacement of the particle is permanently zero, called displacement nodes.
2. the vibrations of the particles between successive displacement nodes are in phase. Hence, when one particle is at its maximum displacement, all particles are then at their maximum displacements. When a particle (other than the displacement node) has zero displacement, all particles then have zero displacement.
3. each particle has a different amplitude of vibration from neighboring particles. Particles which have the greatest amplitude are at the antinodes.

(d) An example of a progressive longitudinal wave is the sound wave, produced by a tuning fork, travelling from the tuning fork to another place.

An example of a stationary longitudinal wave is the sound wave produced by blowing across the mouth of a wind instrument such as the flute.

(e) (i) Two sets of diffraction patterns due to the two wavelengths would be observed. The zeroth order bright fringe will be observed at the straight through position.

$$d\sin\theta_n = n\lambda$$

$$\sin\theta_n = \frac{n\lambda}{d}$$

$$\theta_n = \sin^{-1}\left(\frac{n\lambda}{d}\right) \text{where } \frac{1}{d} = 500.$$

(c) (i) Students often confuse position with displacement in a longitudinal wave. The position refers to the location of a particle with respect to a reference point. The displacement refers to how far away from and the direction with respect to the equilibrium position of a particle. Note that the sketch shows the situation at one particular time i.e. it is a 'snapshot' in time.

(d) Other examples of progressive longitudinal waves:

1. the wave produced on a slinky when you vibrate it along the length of the slinky.
2. the ultrasound waves used in ultrasonic body scanning techniques.

(e) (i) d = separation between adjacent slits

$= \dfrac{1}{\text{no. of lines per unit length}}$

For $\lambda = 588.99$ nm,

the first order bright fringe is at:

$$\theta_1 = \sin^{-1}(1 \times 588.99 \times 10^{-9} \times 500)$$
$$= 0.0169°$$

the second order bright fringe is at :

$$\theta_2 = \sin^{-1}(2 \times 588.99 \times 10^{-9} \times 500)$$
$$= 0.0337°$$

And so on.

For $\lambda = 589.59$ nm,

the first order bright fringe is at:

$$\theta_1 = \sin^{-1}(1 \times 589.59 \times 10^{-9} \times 500)$$
$$= 0.0169°$$

i.e. it coincides with the first order bright fringe for the $\lambda = 588.99$ nm light

the second order bright fringe is at :

$$\theta_2 = \sin^{-1}(2 \times 589.59 \times 10^{-9} \times 500)$$
$$= 0.0338°$$

i.e. it is very close to the first order bright fringe for the $\lambda = 588.99$ nm light.

And so on.

(ii) The maximum angular separation between the light of the two wavelengths would occur between the corresponding lines for the largest order that is observable theoretically.

The largest order occurs where $\theta = 90°$,

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

For $\theta = 90°$

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

For $\lambda = 588.99$ nm,

$$n_{max} = \frac{1}{500 \times 588.99 \times 10^{-9}} = 3395$$

For $\lambda = 589.59$ nm,

$$n_{max} = \frac{1}{500 \times 589.59 \times 10^{-9}} = 3392$$

Hence, the maximum angular separation between the light of the two wavelengths for $n = 3392$.

Maximum angular separation

$= \sin^{-1}(3392 \times 589.59 \times 10^{-9} \times 500) - \sin^{-1}(3392 \times 588.99 \times 10^{-9} \times 500)$

$= 2.05°$

(iii) The problem that would be likely to arise in observing the spectral lines of the order $n = 3392$ is that these lines may be too faint to be observed clearly.

(e) (iii) The intensity of higher order spectral lines are lower than that for lower order spectral lines.

Another problem that could arise is the difficulty in counting such a large number of fringes.

Question 5

(a) (i) Describe the motion of one particle in a *transverse* progressive wave. [2]

(ii) Sketch suitable graphs, with labelled axes, for a sinusoidal wave to illustrate what is meant by

1. amplitude A,
2. wavelength λ,
3. period T. [4]

(iii) Show that the speed v of a wave is related to its frequency f and wavelength λ by the expression

$$v = f\lambda$$ [3]

(b) Explain the *principle of superposition* of two waves. [2]

(c) Two small sound sources S_1 and S_2 have frequencies 500 Hz and 504 Hz respectively.

Sound from the two sources is detected at point X, as illustrated in Fig. 3.1.

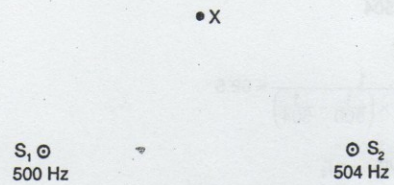


Fig. 3.1

The sound waves from S_1 and S_2 have equal amplitudes A at X.

(i) At time $t = 0$, a wave crest from S_1 meets, at X, a wave crest from S_2. By reference to your answer to **(b)**, state the resultant amplitude at X.

(ii) A short time later, a crest from S_1 meets, at X, with a trough from S_2.

1. Show that crest meets trough at X at time $t = 0.125$ s.
2. State the resultant amplitude at X at $t = 0.125$ s.
3. Suggest what would be heard at X during the time interval between $t = 0$ and $t = 1.0$ s [6]

(d) **(i)** Explain the meaning of *coherence* in relation to the superposition of two waves.

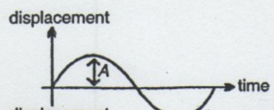
(ii) Suggest why a variation of resultant amplitude is heard in **(c)** although the two sources are not coherent. [3]

[J01/P3/Q3]

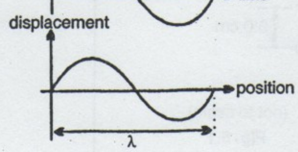
Suggested Solution:

(a) **(i)** It oscillates in a direction that is perpendicular to the direction of travel of the wave.

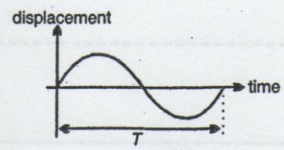
(ii) 1.



2.



3.



(iii) Speed $= \dfrac{\text{Distance moved in one cycle}}{\text{Time taken in one cycle}}$

$= \dfrac{\lambda}{T}$

$= f\lambda$ where $f = \dfrac{1}{T}$

(b) When two waves meet, the resultant displacement is equal to the scalar sum of their individual displacements.

(c) (i) Resultant amplitude at X at $t = 0$ s

= Amplitude of wave from S_1 at X + Amplitude of wave from S_2 at X

= $A + A = 2A$

(ii) 1. A crest from S_1 first meets a trough from S_2 when

$$nT_1 = \left(n+\frac{1}{2}\right)T_2$$

$$n\frac{1}{500} = \left(n+\frac{1}{2}\right)\frac{1}{504}$$

$$n\left(\frac{1}{500}-\frac{1}{504}\right) = \frac{1}{2\times 504}$$

$$n = \frac{1}{2\times 504\times\left(\frac{1}{500}-\frac{1}{504}\right)} = 62.5$$

Hence, the time when this occurs $= nT_1$

$$= 62.5\times\frac{1}{500} = 0.125 \text{ s}$$

2. Resultant amplitude at X at $t = 0.125$ s is $A - A = 0$.

3. The sound heard at X will vary from loudest to decreasing loudness to silence to increasing loudness to the loudest and so on. The sound is loudest when a crest from S_1 meets crest from S_2. Silence occurs when a crest from S_1 meets a trough from S_2 and vice versa.

(c) (ii) 1. S_2 has a higher frequency than S_1. In order for a trough from S_2 to meet a crest from S_1 at X, the wave from S_2 has to lead the wave from S_1 by half a cycle at X.

(d) (i) Two waves are said to be coherent when there is a fixed phase difference between the waves so that there are well-defined maxima and minima when the two waves undergo superposition.

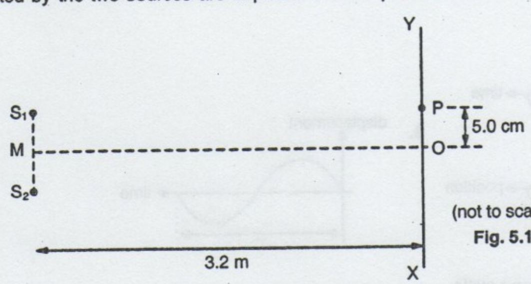
(ii) Although the two sources are not coherent, they produce waves of slightly different frequencies which interfere in a way such that the amplitude of the resultant wave at a given point is not constant but varies with time.

(d) (ii) The varying amplitude gives rise to variations in loudness which are called beats.

Question 6

(a) State what is transferred by a *progressive* wave. [1]

(b) Two microwave sources S_1 and S_2 are situated as shown in Fig. 5.1. The waves emitted by the two sources are in phase and are polarised in the same plane.



(not to scale)

Fig. 5.1

A microwave detector is placed on a line XY which is parallel to, and 3.2 m from, the line joining S_1 and S_2. M is the midpoint of the line joining S_1 and S_2. The line from M perpendicular to the line S_1S_2 meets XY at O. The detector produces an output which is proportional to the displacement of the wave.

With only S_1 switched on, the change with time of the detector output measured at P, a distance of 5.0 cm from O, is as shown in Fig. 5.2

The waveform detected at P for S_2 only is also shown on Fig. 5.2.

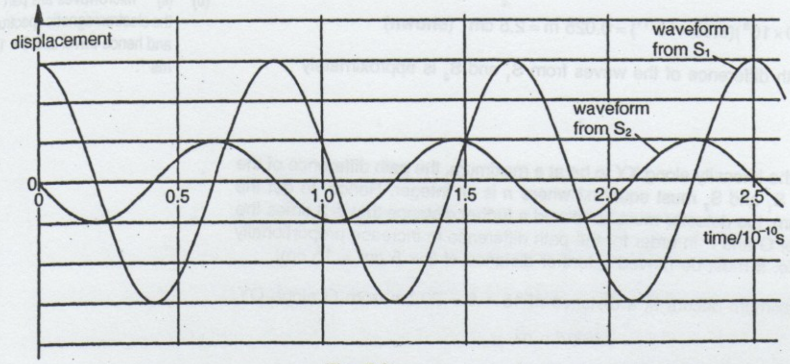


Fig. 5.2

(i) Use Fig. 5.2 to determine

1. the period of the waves,

2. the phase difference between the waves of P,

3. the ratio

$$\frac{\text{intensity at P of wave from } S_1}{\text{intensity at P of wave from } S_2}.$$ [4]

(ii) Using your answer to **(i)1.**, show that the wavelength of the microwaves from S_1 and S_2 is 2.5 cm.

(iii) S_1 and S_2 are switched on together, with the emitted waves in phase. The detector is moved from P along the line OY, in the direction away from O. State and explain the approximate distance that the detector must be moved before the intensity is a maximum, given that there is no maximum between O and P. [3]

(iv) Make an estimate of the separation of the sources S_1 and S_2. [2]

[D01/P2/Q5]

Suggested Solution:

(a) Energy

(b) (i) 1. From Fig. 5.2,

14.2 cm represents 2.0×10^{-10} s.

$\therefore$ 1 cm represents $\frac{2.0 \times 10^{-10}}{14.2}$ s.

Time taken to complete 1 cycle for $S_1 = 5.95 \times \frac{2.0 \times 10^{-10}}{14.2}$

$= 8.38 \times 10^{-11}$ s

$\therefore$ The period of the waves 8.38×10^{-11} s

2. Phase difference between the waves at P $= \frac{\text{time difference}}{\text{period}} \times 2\pi$

$= \frac{1.45}{5.95} \times 2\pi = 1.53$ rad.

3. Intensity $\propto$ (Amplitude)²

$$\Rightarrow \frac{\text{intensity at P of wave from } S_1}{\text{intensity at P of wave from } S_2} = \frac{(\text{Amplitude})^2 \text{ at P of wave from } S_1}{(\text{Amplitude})^2 \text{ at P of wave from } S_2}$$

$$= \frac{(3.0)^2}{(1.0)^2} = 9$$

(b) (i) 1: By measurement, the waves from S_1 and S_2 have the same period.

2. On Fig. 5.2, the distance between the crests of S_1 and S_2 is 1.45 cm. You can use the ratio of $\frac{1.45}{5.95}$ to get your answer, without converting the ratio to a ratio of times.

(ii) $v = \frac{\lambda}{T}$

$\lambda = vT = (3.0\times10^8)(8.38\times10^{-11}) = 0.025$ m $= 2.5$ cm **(shown)**

(b) (ii) Microwaves are part of the electromagnetic spectrum and hence travel at 3.0×10^8 ms^{-1}.

(iii) At P, the path difference of the waves from S_1 and S_2 is approximately

$\frac{1.5}{6.0}\lambda = \frac{1}{4}\lambda.$

In order for the intensity along XY to be at a maximum, the path difference of the waves from S_1 and S_2 must equal $n\lambda$ where n is an integer. Hence, to get the first maximum, the detector must be moved a further distance that is 3 times the separation of O and P in order for the path difference to increase proportionally to 1λ. Hence, it must be moved a further distance of 3 × 5 cm = 15 cm.

(iv) The first maximum occurs at a distance of 15 + 5 = 20 cm from O along OY.

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

where d is the separation between S_1 and S_2.

For the first maximum,

$$d = \frac{n\lambda}{\sin\theta} = \frac{1\times2.5\times10^{-2}}{\frac{0.2}{3.2}} = 0.4 \text{ m}$$

Question 7

Data about stars are almost all provided from measurements involving waves in the electromagnetic spectrum.

(a) Name **five** regions of the electromagnetic spectrum and give the order of magnitude of the wavelength for each of your chosen regions. [5]

(b) State **two** features of electromagnetic waves which are common across the whole spectrum. [2]

(c) A diffraction grating having 300.0 lines per millimeter is used to observe monochromatic light from the hydrogen spectrum, it is found that the first order diffraction pattern occurs at an angle of 8.385°. Calculate the wavelength of the light. [3]

(d) When an astronomer observes the hydrogen spectrum in light from a distant star, the corresponding angle to that in **(c)** is 8.388°,

(i) Calculate the wavelength in this case.

(ii) Calculate the percentage change which has occurred in the wavelength.

(iii) Suggest why this change in wavelength is called red shift. [6]

(e) For greater accuracy, the astronomer wishes to change the method in **(c)** so as to increase the difference between the two angles quoted in **(c)** and **(d)**. Suggest

(i) two ways in which the method may be changed.

(ii) two difficulties the astronomer might encounter. [4]

[D01/P3/Q3]

Suggested Solution:

(a)

Region of electromagnetic spectrum	Order of magnitude of wavelength
ultraviolet	10^{-9} m
visible	10^{-7} m
infra-red	$10^{-7} \sim 10^{-4}$ m
micro-waves	$10^{-4} \sim 10^{-1}$ m
radio waves	$1 \sim 10^{3}$ m

(b) Two features common across the whole spectrum:

1. The waves travel at a speed of 3.00×10^{8} ms^{-1}.
2. The waves can travel in a vacuum.

(b) All electromagnetic waves travel at the speed of light and can travel in a vacuum.

(c) $d\sin\theta = n\lambda$ where d : separation between the lines on the grating.

$$d = \frac{1}{300 \text{ lines per mm}} = \frac{10^{-3}}{300} \text{ m}$$

Given $\theta = 8.385°$ when $n = 1$,

$$\lambda = \frac{d\sin\theta}{n} = \frac{10^{-3}}{300} \times \frac{\sin(8.385°)}{1} = 486.1 \times 10^{-9} \text{ m}$$

(d) (i) If $\theta = 8.388°$ when $n = 1$,

$$\lambda = \frac{10^{-3}}{300} \times \frac{\sin(8.388°)}{1} = 486.3 \times 10^{-9} \text{ m}$$

(ii) Percentage change $= \frac{486.3 - 486.1}{486.1} = 100\% = 0.041\%$

(iii) There is an increase in wavelength, bringing the value of the wavelength closer to the red end of the visible spectrum. Hence, the change in wavelength is called *red shift*.

(d) (iii) In the visible light spectrum, red has the longest wavelength. Hence, the increase in wavelength is called '*red shift*'.

(e) (i) Two ways in which the methods in (c) may be changed:

1. Use a diffraction grating having a greater number of lines per millimetre so that the angles measured can be larger, so as to reduce the fractional error in measuring the angle.
2. Instead of measuring the angle for the first order diffraction pattern, measure the angle for a higher order diffraction pattern for both the monochromatic light as well as from the distant star.

(ii) Two difficulties the astronomer might encounter:

1. The intensity of the diffraction pattern may fall.
2. Higher order diffraction patterns may be too dim for the angles to be mea sured accurately.

Question 8

(a) Figs. 7.1(a) and (b) show plane wavefronts approaching a narrow gap and a wide gap respectively.

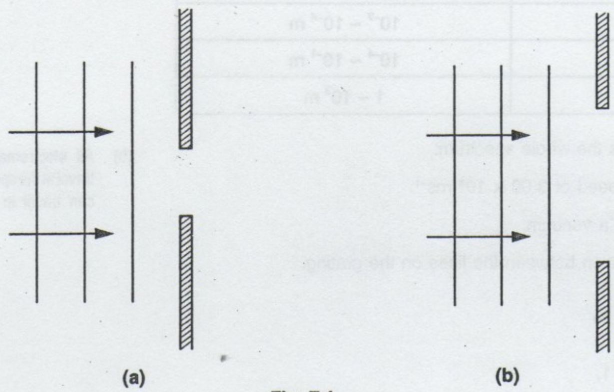


Fig. 7.1

On Figs. 7.1(a) and (b), draw three successive wavefronts to represent the wave after it has passed through each of the gaps. [5]

(b) Light from a laser is directed normally at a diffraction grating, as illustrated in Fig.7.2.

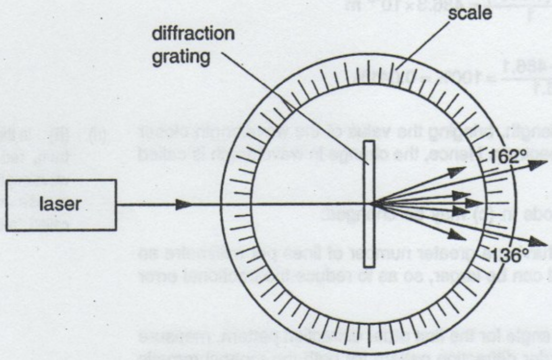


Fig. 7.2

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.

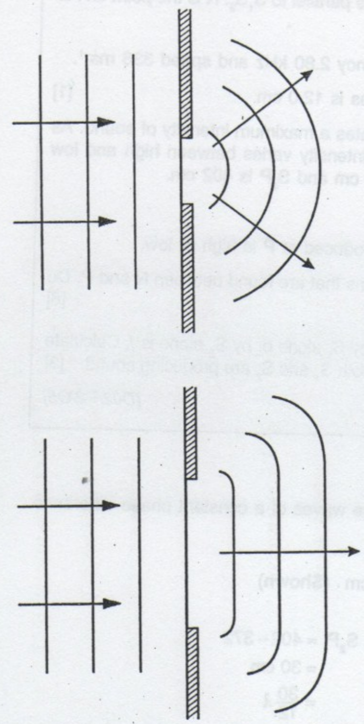
Calculate the spacing of the slits of the diffraction grating. [4]

(c) Suggest one reason why the fringe pattern produced by light passing through a diffraction grating is brighter than that produced from the same source with a double slit. [1]

[J02/P2/Q7]

Suggested Solution:

(a)



(a) In case (a), the degree of diffraction of the waves is larger than that for case (b). This is because the gap/ aperture in case (a) is very close to the wavelength of the wavefronts whereas the aperture in case (b) is roughly thrice the wavelength.

When drawing the three successive wavefronts after the wave has passed through the aperture, ensure that the distance between successive wavefront is the same as that before the wave has passed through the aperture.

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

$\therefore$ spacing of the slits of the diffraction grating,

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

$$= \frac{2 \times (630 \times 10^{-9})}{\sin\left(\frac{1}{2}(162° - 136°)\right)} = 5.6 \times 10^{-6} \text{ m}$$

(b) $\theta = \frac{1}{2}$ (the angle subtended by the diffracted beams of the same order)

$\therefore \theta = \frac{1}{2}(162° - 136°)$ for the second order beams.

(c) There are much greater number of slits on a diffraction grating than on a double-slit. Diffraction occurs at each of the slits, leading to interference. The greater occurrence of constructive interference for a diffraction grating gives rise to a brighter fringe pattern.

Question 9

(a) Explain what is meant by *coherent* sources. [1]

(b) Two small coherent sound sources S_1 and S_2 are set up as shown in Fig. 5.1.

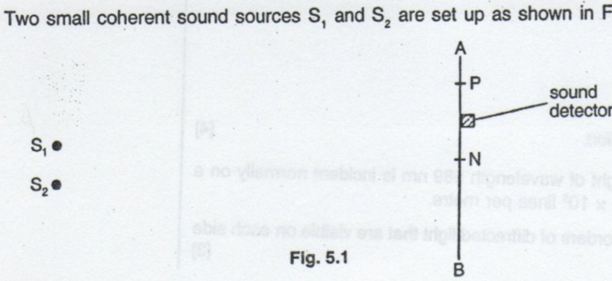


Fig. 5.1

A sound detector is moved along a line AB that is parallel to S_1S_2. N is the point on AB such that $S_1N = S_2N$.

The sound waves from S_1 and S_2 have frequency 2.80 kHz and speed 336 ms^{-1}.

(i) Show that the wavelength of the waves is 12.0 cm. [1]

(ii) The detector, when placed at N, indicates a maximum intensity of sound. As it is moved from N to a point P, the intensity varies between high and low values. At P, the distance S_1P is 372 cm and S_2P is 402 cm.

Determine, with suitable explanation,

1. whether the intensity of sound produced at P is high or low,

2. the number of high intensity regions that are found between N and P. Do not include the maximum at N. [6]

(iii) The intensity of sound produced at N by S_1 alone or by S_2 alone is *I*. Calculate the intensity at N, in terms of *I*, when both S_1 and S_2 are producing sound. [3]

[D02/P2/Q5]

Suggested Solution:

(a) *Coherent sources* are sources that produce waves of a constant phase difference.

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

$$\lambda = \frac{v}{f} = \frac{336}{2.80 \times 10^3} = 0.12 \text{ m, i.e. } 12 \text{ cm}$$ **(Shown)**

(ii) **1.** Path difference between S_1P and S_2P $= 402 - 372$

$= 30$ cm

$= \frac{30}{12}\lambda$

$= 2.5\lambda$

Since the path difference is not an integral multiple of the wavelength of the sound, destructive interference occurs at P and the intensity of sound at P is low.

2. Since $S_2P - S_1P = 2.5\lambda$, then there are two regions of high intensity between N and P, excluding that at N.

$\therefore$ Number = 2

(iii) Intensity $\propto$ (Amplitude)^2

If the amplitude of S_1 alone = amplitude of S_2 alone = *A*, then amplitude of sound at N when both S_1 and S_2 are producing sound = $A + A = 2A$

Intensity at N = $(2A)^2$

$= 4A^2$

$= 4I$

Question 10

(a) Explain what is meant by

(i) the *diffraction* of a wave,

(ii) the *principle of superposition*. [4]

(b) A narrow beam of coherent light of wavelength 589 nm is incident normally on a diffraction grating having 4.00×10^5 lines per metre.

(i) Determine the number of orders of diffracted light that are visible on each side of the zero order. [3]

(ii) A student suspects that there are two wavelengths of light in the incident beam, one at 589.0 nm and the other at 589.6 nm.

1. State the order of diffracted light at which the two wavelengths are most likely to be distinguished.
2. The minimum angular separation of the diffracted light for which two wavelengths may be distinguished is 0.10°. Make calculation to determine whether the student can observe the two wavelengths as separate images. [4]

[D03/P2/Q5]

Suggested Solution:

(a) (i) *Diffraction* refers to the bending and spreading of waves when they pass through an aperture or go around an obstacle. It is observed when the wavelength of the wave is comparable to the width of the aperture.

(ii) The *Principle of Superposition* state that the resultant displacement at any point when two waves travel through a medium is the sum of the separate displacements due to the two waves.

(b) (i) $d\sin\theta = n\lambda$

If $\theta = 90°$,

$$n = \frac{d\sin\theta}{\lambda} = \frac{\frac{1}{4.00\times10^5}\sin 90°}{589\times10^{-9}} = 4.24$$

Hence, the number of orders that are visible on each side of the zero order is 4.

(ii) 1. The fourth order

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

For the 4th order belonging to 589.0 nm light,

$$\sin\theta_1 = \frac{n\lambda}{d}$$

$$\therefore\ \theta_1 = \sin^{-1}(4\times589\times10^{-9}\times4.00\times10^5) = 70.46°$$

For the 4th order belonging to 589.6 nm light,

$$\sin\theta_2 = \frac{n\lambda}{d}$$

$$\therefore\ \theta_2 = \sin^{-1}(4\times589.6\times10^{-9}\times4.00\times10^5) = 70.62°$$

Angle subtended by the two lines $= \theta_2 - \theta_1$

$= 70.62° - 70.46°$

$= 0.16° > 0.10°$

Since this angle is larger than the minimum angular separation that may be distinguished, the student can observe the two wavelengths as separate images.

(b) (ii) 1. The amount of spreading increases as the order increases. Hence it is likely that the fourth order lines of the two wavelengths are further apart than any of the other respective orders.

Question 11

(a) The wavelength of sound in air is of the order of one million times greater than the wavelength of light in air. Describe how you could check this statement experimentally. [8]

(b) (i) Show how the principle of superposition of waves can be used to explain the formation of two-source interference fringes. [3]

(ii) Two-source interference fringes using light can only be obtained if light from the two sources is coherent. Explain

1. the meaning of the term *coherent*, [1]
2. why, in practice, interference fringes can be seen only if light from a single source is split into two. [2]

(iii) Coherent, monochromatic light from two narrow slits a distance 0.38 mm apart causes an interference pattern on a screen 1.20 m from the slits, as illustrated in Fig. 3.1.

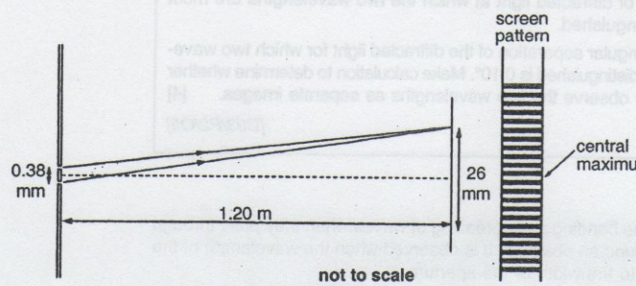


Fig. 3.1

The distance from the sixth bright fringe on one side of the pattern to the sixth bright fringe on the other side of the pattern is found to be 26 mm. Calculate the wavelength of the monochromatic light. [3]

(iv) State the experimental advantage gained by determining the fringe width in the way that was used in **(iii)**. [1]

(v) Another way of obtaining fringes similar to those described in **(iii)** is illustrated in Fig. 3.2.

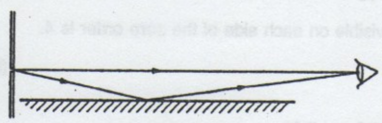


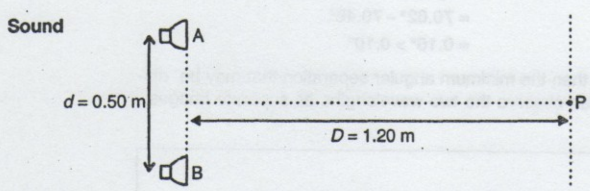
Fig. 3.2

A single slit is viewed both directly and by reflection from a mirror surface. Explain why this system produces a fringe pattern. [2]

[D04/P3/Q3]

Suggested Solution:

(a) I would make use of the fact that waves can undergo interference to check this statement. I would use Young's double-slit set-up for both sound and light waves in air, as described in the following.



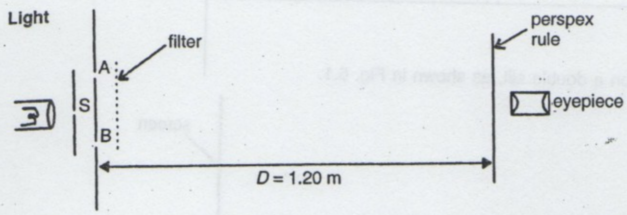
- Connect sound waves of a single frequency from the same signal generator to two small loudspeakers A and B.
- Place a small sensitive microphone at P and connect it via a pre-amplifier to a cathode ray oscilloscope (CRO).
- Place A and B about 0.5 m apart and equidistant to P. Place P about 1.2 m away from A and B.
- Move the microphone parallel to the line joining A and B. Observe the traces on the CRO showing the maxima and minima obtained due to the interference of sound waves from A and B. Measure y (see below).

– Calculate wavelength of sound using $\lambda_s = \frac{yd}{D}$

where y : separation between adjacent maximum and minimum as indicated by the CRO traces.

d : separation between A and B.

D : perpendicular distance between A and B and P.



– Focus light from a small filament lamp onto a narrow slit S, such that in the collimator of a spectrometer.
– Place two narrow slits A, B about 0.5 mm apart and a short distance in front of S.
– View the light coming from A, B in a low-powered microscope or eyepiece about 1.2 m away.
– Place a filter between A, B and the microscope so that fringes of a particular colour can be seen.
– Place a Perspex rule in front of the eyepiece and move it until the graduations are clearly seen.
– Measure the average distance, y, between the fringes using the graduations.
– Measure the distance, d, between the slits A and B using a travelling micro scope.
– Measure the distance, D, using a metre rule.
– Calculate the wavelength of the light using

$$\lambda_l = \frac{yd}{D}.$$

Hence, compare λ_s and λ_l to check whether the wavelength of sound in air, λ_s, is of the order of one million times greater than the wavelength of light in air, λ_l.

(b) (i) When two or more waves travel in the same space, the displacement of any particle at a given time is the sum of the displacements that the individual waves alone would give it. For waves originating from two coherent sources, when a peak meets another peak, a bright fringe is obtained. When a peak meets with a trough, a dark fringe is obtained.

(ii) 1. Light from two sources are said to be coherent if they are of the same frequency (and hence wavelength) and the phase difference between them is always constant.

2. Ordinary light sources emit light that lack coherence due to the fact that the emitting atoms do not act 'cooperatively' or coherently. To get a pair of coherent sources, light from a single source is split into two so that a constant phase difference is always maintained.

(iii) $$\lambda = \frac{yd}{D}$$

y is the distance between 2 fringes.

There are 6 + 1 + 6 = 13 fringes.

Distance between each fringe is $26 \div 13 = 2$ mm.

$$\lambda = \frac{(2\times10^{-3})(0.38\times10^{-3})}{1.20} = 633 \text{ nm}$$

(iv) Fractional error is reduced.

(v) In Fig. 3.2, there are two coherent light sources - the light that travels directly to the eye and the light that is reflected from the mirror surface before travelling to the eye. These two sources will interfere and produce a fringe pattern. Depending on where the eye is positioned, bright or dark fringes can be seen.

Question 12

Coherent light is incident normally on a double slit, as shown in Fig. 6.1.

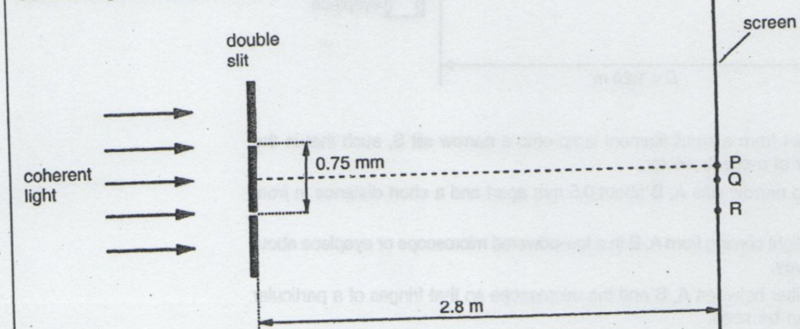


Fig. 6.1 (not to scale)

The separation of the slits in the double-slit arrangement is 0.75 mm.
A screen is placed parallel to, and at a distance of 2.8 m from, the double slit. P is a point on the screen that is equidistant from the two slits.
Fig. 6.2 shows the variation with distance from P of the intensity *I* of the light on the screen.

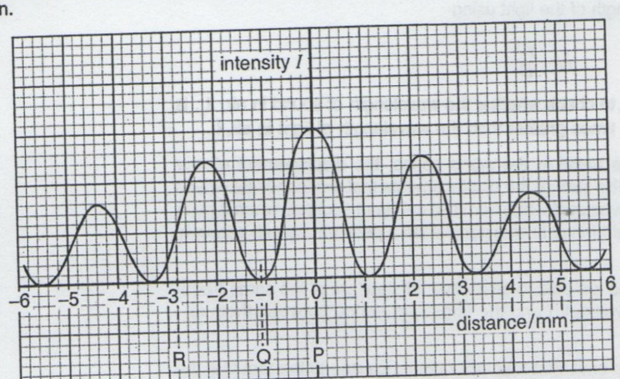


Fig. 6.2

(a) Calculate the wavelength, in nm, of the coherent light. [4]

(b) Points Q and R are points on the screen. Their positions are indicated on Fig. 6.2. Determine the phase angle between the waves from the double slit when the waves meet at.

(i) point Q, phase angle = ... rad [1]

(ii) point R. phase angle = ... rad [2]

(c) Suggest why the maxima on Fig. 6.2 are not all of the same intensity. [2]

[N06/P2/Q6]

Suggested Solution:

(a) $\lambda = \frac{ax}{D}$

From graph, $x = 2.2 - 0 = 2.2$ mm

$\therefore \lambda = \frac{(0.75\times10^{-3})(2.2\times10^{-3})}{2.8} = 5.9\times10^{-7}$ m = 590 nm

(a) Wavelength of visible light is between 400 to 700 nm)

(b) (i) π rad

(ii) R is the midpoint between the 1st maxima (phase difference of 2π) and 2nd minima (phase difference of 3π). Phase difference at R is 2.5π rad.

(c) The maxima further from the zero order will be of lower intensity due to the greater distance from the light source.

Question 13

(a) Fig. 5.1 shows the variation with time t of the displacement y of a wave W as it passes a point P. The wave has intensity I.

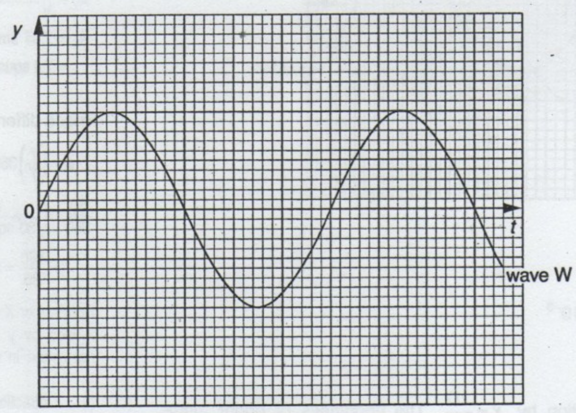


Fig. 5.1

A second wave X of the same frequency as wave W also passes point P.

This wave has intensity $\frac{1}{2}I$. The phase difference between the two waves is 60°.

On Fig. 5.1, sketch the variation with time t of the displacement y of wave X. [3]

(b) In a double-slit interference experiment using light of wavelength 540 nm, the separation of the slits is 0.700 mm. The fringes are viewed on a screen at a distance of 2.75 m from the double slit, as illustrated in Fig. 5.2 (not to scale).

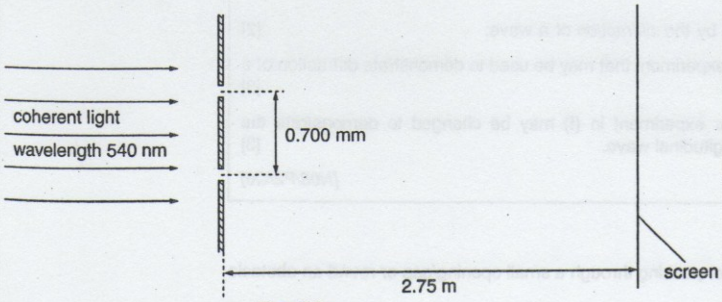


Fig. 5.2

Calculate the separation of the fringes observed on the screen. [3]

(c) State the effect, if any, on the appearance of the fringes observed on the screen when the following changes are made, separately, to the double-slit arrangement in **(b)**.

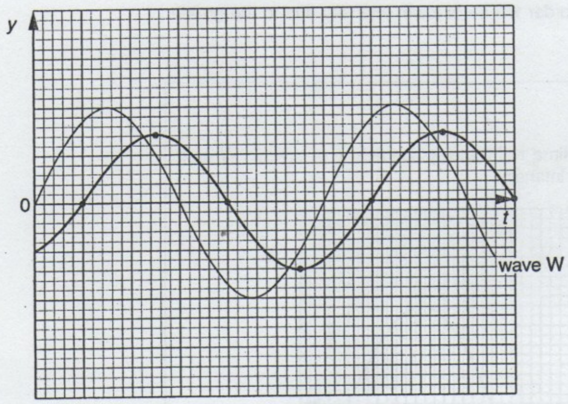
(i) The width of each slit is increased but the separation remains constant. [3]

(ii) The separation of the slits is increased. [2]

[N07/P2/Q5]

Suggested Solution:

(a)



(a) Amplitude of X:

$$\frac{I_X}{I_y} = \frac{A_X^2}{A_y^2}$$

$$\frac{\frac{I}{2}}{I} = \frac{A_X^2}{(10 \text{ squares})^2}$$

$$A_X = \sqrt{\frac{100 \text{ squares}^2}{2}}$$

$A_X = 7.07$ sm

$= 7.1$ squares

Phase difference:

$$\phi = \left(\frac{t}{T}\right)360°$$

$$\frac{60}{360} = \left(\frac{t}{30 \text{ squares}}\right)$$

$$t = \frac{180}{36} = 5 \text{ squares}$$

Here either X leads by y, or X lags by y because it is not asked in question.

(b) $x = \dfrac{\lambda D}{a}$

$$= \frac{(540 \times 10^{-9})(2.75)}{0.700 \times 10^{-3}} = 2.12 \times 10^{-3}$$

∴ separation = 2.12 mm

(c) (i) No change in fringe separation by $x = \dfrac{\lambda D}{a}$. The brightness of bright fringe increases with no change in dark fringe. Therefore contrast increases. Few fringes are observed due to lesser diffraction.

(ii) Fringe separation decreases by $x = \dfrac{\lambda D}{a}$, but there is no change in brightness or darkness of fringes.

(c) (i) Diffraction decreases if the width of slit is greater.

(ii) Contrast will remain same.

Question 14

(a) Explain what is meant by the *diffraction* of a wave. [2]

(b) (i) Outline briefly an experiment that may be used to demonstrate diffraction of a transverse wave. [3]

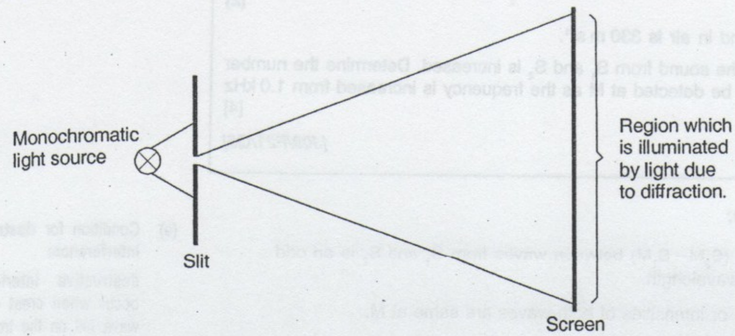
(ii) Suggest how your experiment in (i) may be changed to demonstrate the diffraction of a longitudinal wave. [3]

[N08/P2/Q6]

Suggested Solution:

(a) Spreading of a wave after passing through a small opening/gap or round an obstacle is called diffraction.

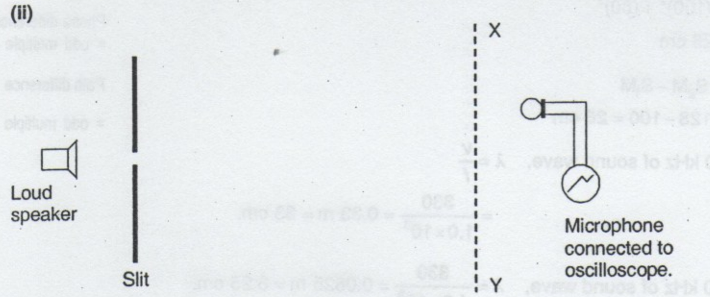
(b) (i)



(b) Distribution of marks is for
1. Source.
2. Detector.
3. Observation.

Light spread out after passing through the slit and cover a wide region on the screen.

(ii)



Longitudinal sound waves from the speaker are spread out from the slit and cover the region XY which is detected by moving a microphone connected to oscilloscope.

Question 15

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

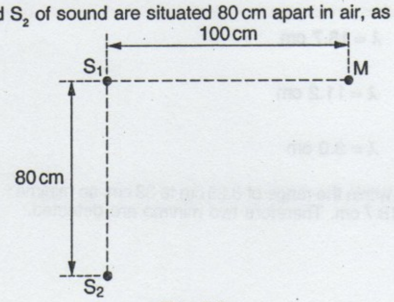


Fig. 5.1

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. [2]

(b) The speed of sound in air is 330 m s⁻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. [4]

[J09/P21/Q5]

Suggested Solution:

(a) 1. Path difference ($S_2M - S_1M$) between waves from S_1 and S_2 is an odd multiple of half wavelength.

2. The amplitudes or intensities of both waves are same at M.

(a) **Condition for destructive interference:**

destructive interference occur when crest of one wave fall on the trough of second to cancel out each other effect by super-position principle.

Phase difference = odd multiple of π

Path difference = odd multiple of $\frac{\lambda}{2}$.

(b) Distance $S_2M = \sqrt{(S_1M)^2 + (S_1S_2)^2}$

$= \sqrt{(100)^2 + (80)^2}$

$= 128$ cm

Path difference $= S_2M - S_1M$

$= 128 - 100 = 28$ cm

wavelength at 1.0 kHz of sound wave, $\lambda = \frac{v}{f}$

$= \frac{330}{1.0 \times 10^3} = 0.33\text{ m} = 33\text{ cm}.$

wavelength at 4.0 kHz of sound wave, $\lambda = \frac{330}{4.0 \times 10^3} = 0.0825\text{ m} = 8.25\text{ cm}.$

Path difference for minima $= (2n+1)\frac{\lambda}{2}$

$\Rightarrow \quad 28 = (2n+1)\frac{\lambda}{2}$

put $n = 0$, $\quad 28 = (2(0)+1)\frac{\lambda}{2} \quad \Rightarrow \quad \lambda = 56$ cm

put $n = 1$, $\quad 28 = (2(1)+1)\frac{\lambda}{2} \quad \Rightarrow \quad \lambda = 18.7$ cm

put $n = 2$, $\quad 28 = (2(2)+1)\frac{\lambda}{2} \quad \Rightarrow \quad \lambda = 11.2$ cm

put $n = 3$, $\quad 28 = (2(3)+1)\frac{\lambda}{2} \quad \Rightarrow \quad \lambda = 8.0$ cm

Since wavelength 56 cm and 8.0 cm are not within the range of 8.25 cm to 33 cm, so minima is obtained for wavelengths 11.2 cm and 18.7 cm. Therefore two minima are detected.

Question 16

A double-slit interference experiment is set up using coherent red light as illustrated in Fig. 5.1.

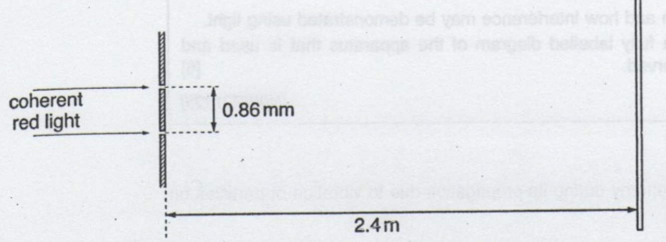


Fig. 5.1 (not to scale)

The separation of the slits is 0.86 mm.
The distance of the screen from the double slit is 2.4 m.
A series of light and dark fringes is observed on the screen.

(a) State what is meant by *coherent* light. [1]

(b) Estimate the separation of the dark fringes on the screen. [3]

(c) Initially, the light passing through each slit has the same intensity. The intensity of light passing through one slit is now reduced. Suggest and explain the effect, if any, on the dark fringes observed on the screen. [2]

[J09/P22/Q5]

Suggested Solution:

(a) Light waves having constant phase angle in-between them.

(b) Separation, $x = \frac{\lambda D}{a}$

$= \frac{(650\times10^{-9})(2.4)}{0.86\times10^{-3}} = 1.81\times10^{-3} = 1.81\text{ mm}$

(b) Wavelength of red light is 650 nm.

(c) Now amplitude of one wave is larger than the other so there is no complete destructive interference and the dark fringes are lighter.

(c) Amplitude of a wave is reduced if the intensity of light passing through one slit is reduced as intensity $\propto$ (amplitude)^2

Question 17

(a) State what is meant by a *progressive wave*. [2]

(b) The variation with distance *x* along a progressive wave of a quantity *y*, at a particular time, is shown in Fig. 5.1.

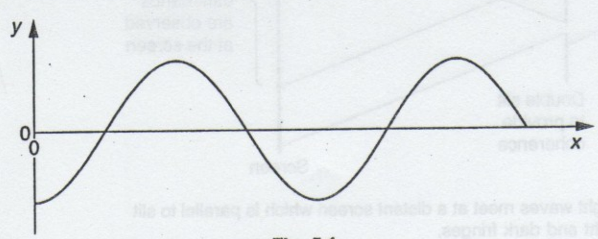


Fig. 5.1

(i) State what the quantity *y* could represent. [1]

(ii) Distinguish between the quantity *y* for

1. a transverse wave, [1]
2. a longitudinal wave. [1]

(c) The wave nature of light may be demonstrated using the phenomena of diffraction and interference.

Outline how diffraction and how interference may be demonstrated using light.

In each case, draw a fully labelled diagram of the apparatus that is used and describe what is observed. [6]

[N09/P21/Q5]

Suggested Solution:

(a) A wave which transfer energy during its propagation due to vibration of particles on the wave.

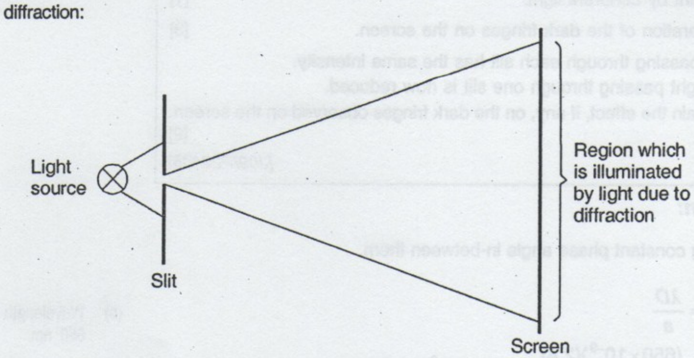
(b) (i) Displacement.

(ii) 1. Displacement of particles is perpendicular to the direction of travel of wave energy.

2. Displacement of particles is parallel to the direction of travel of wave energy

(b) (i) Other correct answers are either 'velocity' or 'acceleration'.

(c) diffraction:



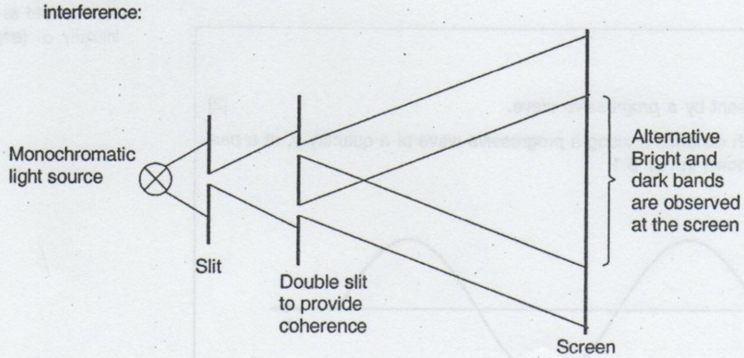
(c) The spreading of light into the geometric shadow region provide evidence of diffraction .

Distribution of marks is for,

1. Source.
2. Detection.
3. Observation.

Place a light source in front of a small aperture. The light through the aperture spread out and a bright region is available on a distant screen where darkness was expected.

interference:



Coherent monochromatic light waves meet at a distant screen which is parallel to slit to provide an alternate bright and dark fringes.