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IB · HL · Physics

7 hours | 43 questions

Structured Questions

Wave Phenomena

Wavefronts & Rays / Reflection, Refraction & Transmission / Diffraction of Waves / Refraction of Waves / Superposition of Waves / Interference of Waves / Young's Double-Slit Experiment / Single-Slit Diffraction (HL) / Diffraction Gratings (HL)

Easy (16 questions)	/159
Medium (16 questions)	/169
Hard (11 questions)	/104
Total Marks	**/432**

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Easy Questions

1 (a) State the distinctive features of a single-slit interference pattern using monochromatic light.

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(2 marks)

(b) The monochromatic light is replaced by a source of white light.

The paragraph below describes how this change would affect the interference pattern. Choose appropriate words to fill the gaps.

The central maximum would be __________, and each subsidiary maximum would be composed of a ___________.

The ___________ wavelength would appear nearest to the central maximum, and the _____________ wavelength would appear furthest from the central maximum.

The fringe spacings would be ___________ and the maxima would be ____________.

....

....

....

(3 marks)

(c) The white light source is replaced, first with red laser light and then blue laser light.

Explain the difference in the diffraction patterns between the red and blue light.

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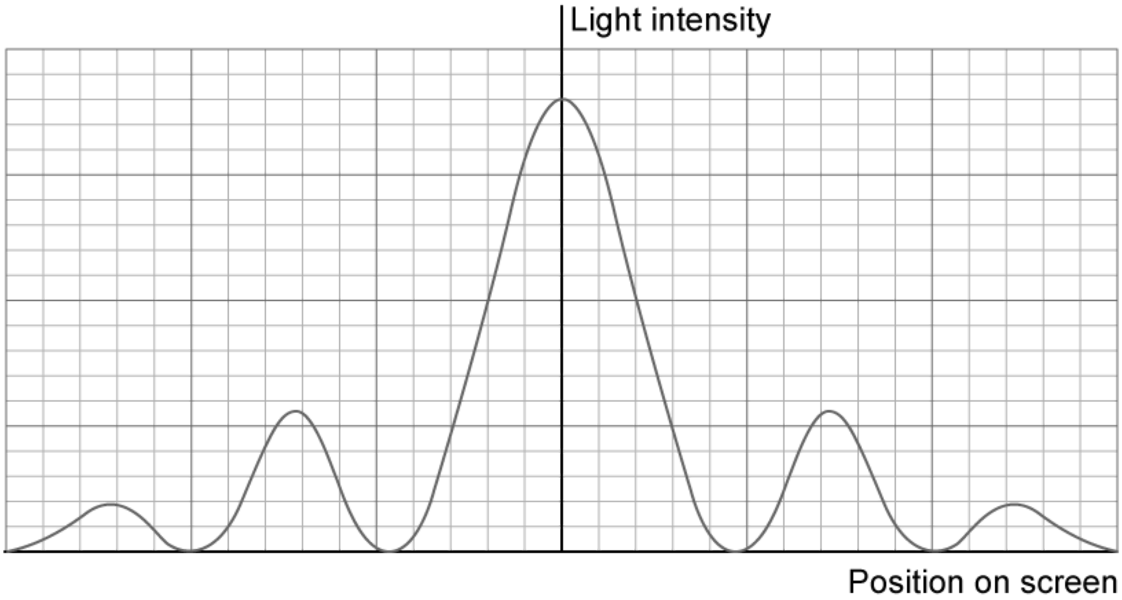
(2 marks)

(d) The diagram below shows the intensity patterns for blue light.



On the same axes, sketch the intensity pattern for red light.

....

....

(2 marks)

2 (a) The angle of diffraction of the first minima can be found using the following equation:

$$\theta = \frac{\lambda}{b}$$

State the definition of each variable and give an appropriate unit for each.

....

(1 mark)

(b) Use the equation from part (a) to determine what will happen to the angle of diffraction if the width of slit is doubled using monochromatic light.

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(3 marks)

(c) Use the equation from part (a) to explain why red light produces wider maxima than blue light.

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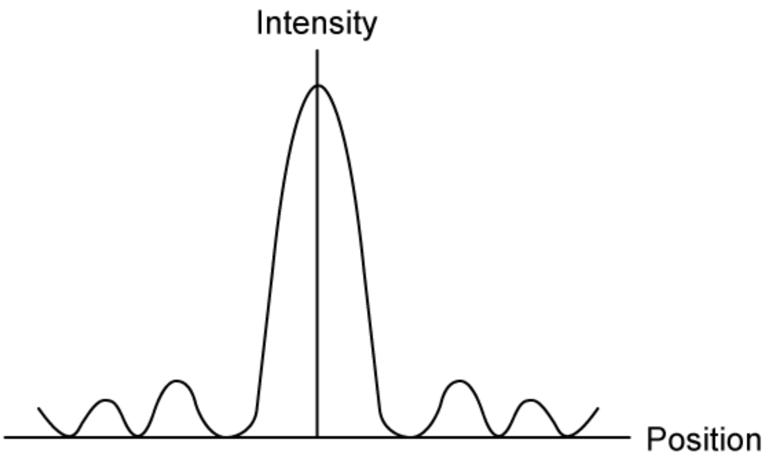
(2 marks)

(d) The graph below shows the diffraction pattern of monochromatic red light with a slit width *b*.



Sketch on the same axes the diffraction pattern if the slit width was reduced.

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(2 marks)

3 (a) For the diffraction of light through a single slit, the following equation is used:

$$\theta = \frac{\lambda}{b}$$

The equation contains some assumptions about the set up of the equipment.

(i) Outline why the slit width has to be has to be smaller than the wavelength of the incident light.

[1]

(ii) Explain why the screen must be placed a great distance away from the slit.

[2]

(3 marks)

(b) Monochromatic light of wavelength 450 nm is incident upon a single slit of width 1.3 μm. Determine the angle of diffraction.

(4 marks)

(c) State the colour of the light used in the experiment in part (b).

(1 mark)

(d) Determine the angular width of the central maximum for the experiment in part (b).

(2 marks)

4 (a) A group of students were conducting single-slit diffraction experiments with different coloured lasers.

A slit width of 0.12 mm was used, but the student forgot to note down what colour laser was used. The angle of diffraction produced was 0.0050 rad. Determine the colour of the incident light.

(4 marks)

(b) The students decided to try the red laser next. Suggest, without calculation, how this would affect the diffraction pattern.

(4 marks)

(c) Calculate the angle of diffraction using the red laser of wavelength 675 nm.

(3 marks)

(d) Still using the same red laser, the students discussed the effect of decreasing the slit width by half.

(i) State a prediction of the effect this would have on the diffraction pattern.

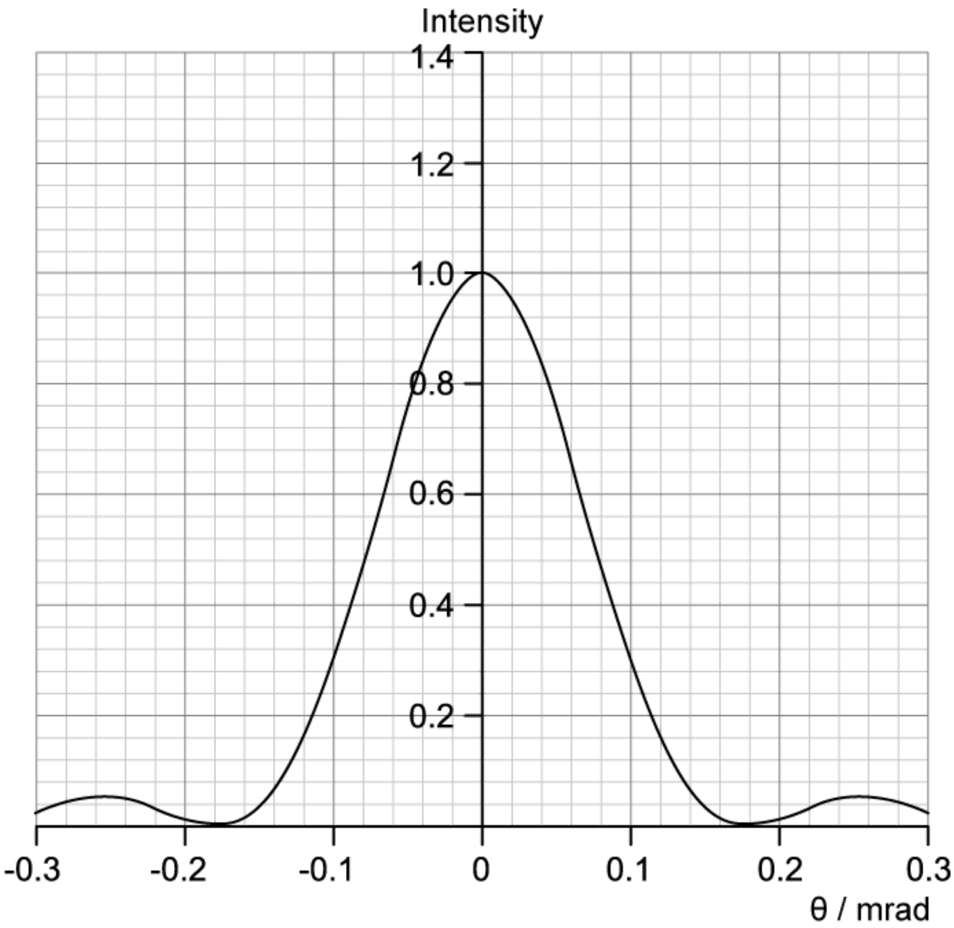
[3]

(ii) Prove mathematically that your prediction would be correct.

[4]

(7 marks)

5 (a) The following graph shows the diffraction pattern for monochromatic light incident on a single slit.



The wavelength of the light used is 4.5×10^{-7} m. Calculate the width of the slit.

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(4 marks)

(b) The investigation from part (a) was repeated. The same light was used, but the slit width was doubled.

On the same graph shown in part (a) sketch the resulting diffraction pattern for the new slit width.

(3 marks)

(c) Using the same light from parts (a) and (b), determine the slit width that would give the central maximum an angular width of 0.1 mrad.

(4 marks)

(d) Light with wavelength λ is incident upon a single slit of width b producing an angle of diffraction θ.

Explain the change in the diffraction pattern if light with a wavelength $\frac{\lambda}{2}$ and a slit width $\frac{b}{2}$ were used.

(3 marks)

6 (a) Outline what is meant by the terms

(i) Wavefront

[2]

(ii) Ray

[1]

....

....

....

(3 marks)

(b) Complete the following sentence by placing a tick (✓) next to the correct answer:

The distance between two consecutive wavefronts is equal to the:

	wavelength
	frequency
	amplitude

....

(1 mark)

(c) On the grid below, draw scale diagrams showing the wavefronts for

(i) A plane wave with a wavelength of 1 cm.

[2]

(ii) A circular wave with a wavelength of 1 cm.

[2]

On both diagrams, show with arrows, the direction of propagation.

(4 marks)

(d) Complete the following sentences by circling the correct word:

The higher the frequency of an oscillation, the **longer / shorter** the wavelength and the **closer / further apart** the wavefronts are **to / from** one another.

The lower the frequency of the oscillation, the **longer / shorter** the wavelength and the **closer / further apart** the wavefronts are **to / from** one another.

(2 marks)

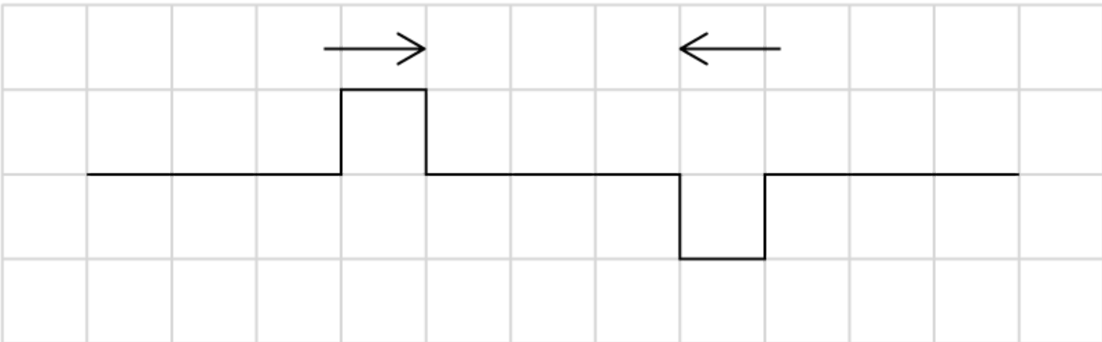
7 (a) Outline what is meant by the principle of superposition.

....

....

(2 marks)

(b) Two pulses travel toward one another as shown in the diagram.

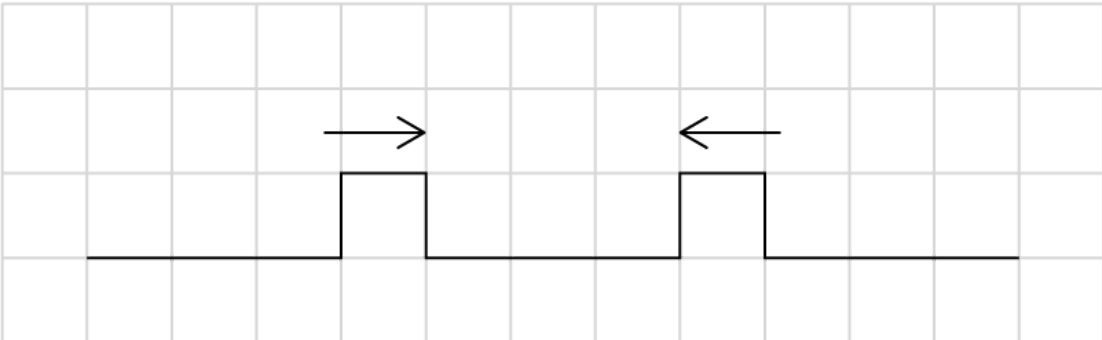


Sketch the resultant displacement as the pulses superpose.

....

(1 mark)

(c) Two pulses travel in opposing directions as shown in the diagram. When the pulses meet, they superpose.



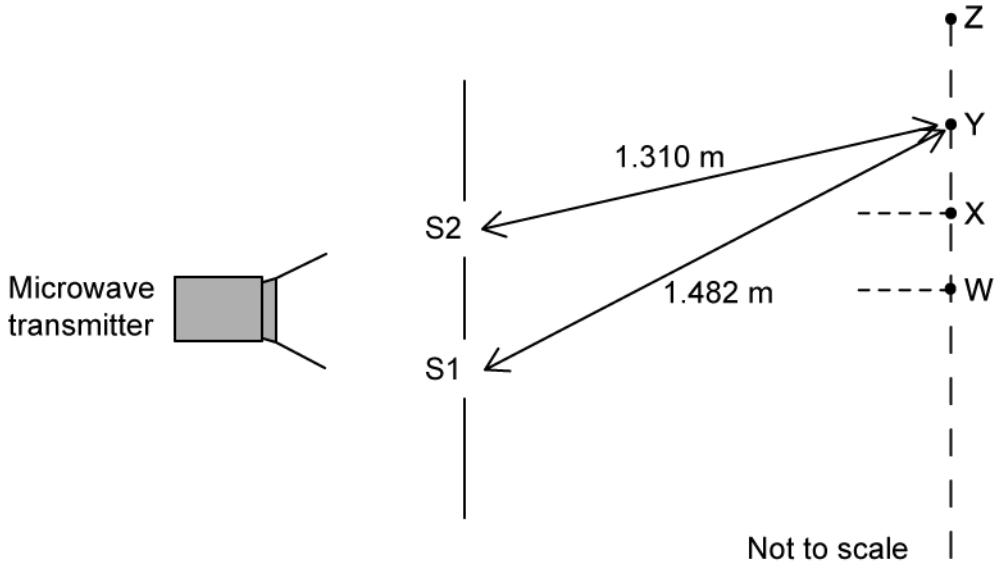
Draw the resultant peak as the pulses superpose.

(1 mark)

(d) Distinguish between the terms constructive interference and destructive interference.

(4 marks)

A beam of microwaves is incident normally on a pair of identical narrow slits S1 and S2.



8 (a) When a microwave receiver is initially placed at W which is equidistant from the slits, a maximum intensity is observed. The receiver is then moved towards Z along a line parallel to the slits. Intensity maxima are also observed at X and Y with one minimum between them. W, X and Y are consecutive maxima.

The distance from S1 to Y is 1.482 m and the distance from S2 to Y is 1.310 m.

(i) Calculate the path difference at Y.

[1]

(ii) Sketch the path difference on the diagram. Label this P.

[2]

(3 marks)

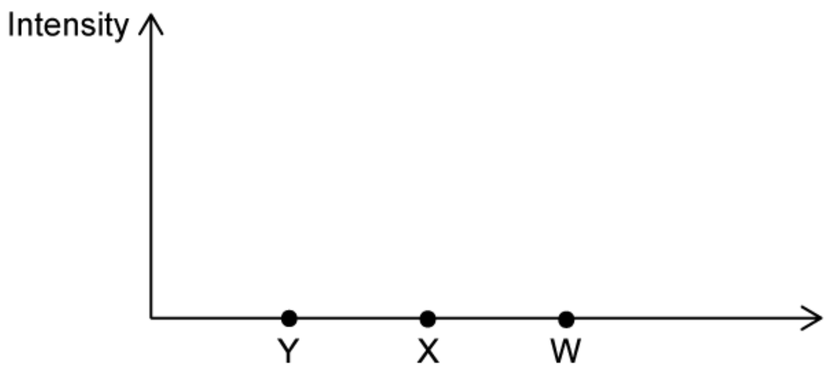
(b) State the condition for intensity maxima to be observed at X and Y.

(1 mark)

(c) State what the intensity maxima and intensity minima represent.

(2 marks)

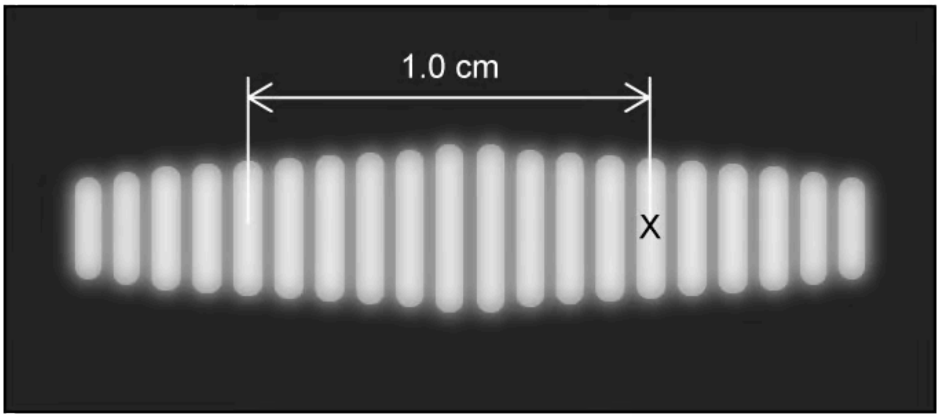
(d) A microwave receiver can be used to detect the interference pattern. This can be visually represented on an intensity-displacement axis.



Sketch the interference pattern for the points W, X and Y.

(3 marks)

9 (a) In an investigation into interference, monochromatic light of wavelength 600 nm is incident normally on a double slit. The fringes seen on a screen positioned at a distance D = 1.5 m from the slits are shown.



Determine the order, n of the bright fringe at X.

....

(1 mark)

(b) For the observation in part (a), sketch a diagram to show the triangle formed by the slits, the screen and the bright fringes.

Include the following information, along with any numerical values, on your diagram:

- Maxima, n
- Distance from double slits to screen, D
- Screen width, S
- Angle of diffraction, θ

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(4 marks)

(c) Without using the angle of diffraction, calculate the separation between the slits.

(5 marks)

(d) Using the diagram from part (b), hence calculate the angle subtended between the slits, the central maxima and the fifth order maxima.

(2 marks)

10 Identify, by placing a tick (✔) in the correct box, the statements about double slit interference patterns that are true.

Statement	**Place a tick (✔) in this box if the statement is true**
For two source interference fringes to be observed the sources of the waves must be coherent	
When two waves interfere the resultant wave depends on the path difference	
When two waves interfere the path difference is proportional to the intensity	
Two source interference fringes are observed when light is monochromatic	

(3 marks)

11 (a) A diffraction grating has 8000 lines and is 4 cm wide.

Calculate the number of lines per meter.

....

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(2 marks)

(b) Hence, use your answer from part (a), to calculate the slit spacing on the diffraction grating and state the units.

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(3 marks)

(c) In an experiment, red light of wavelength 650 nm is incident upon this diffraction grating.

Calculate the angle of diffraction at the second order maximum.

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....

(4 marks)

(d) Determine the equation for the maximum number of fully formed bright fringes that are visible on the screen.

....

....

(2 marks)

12 (a) State what is meant by:

(i) The law of reflection.

[1]

(ii) Refraction.

[1]

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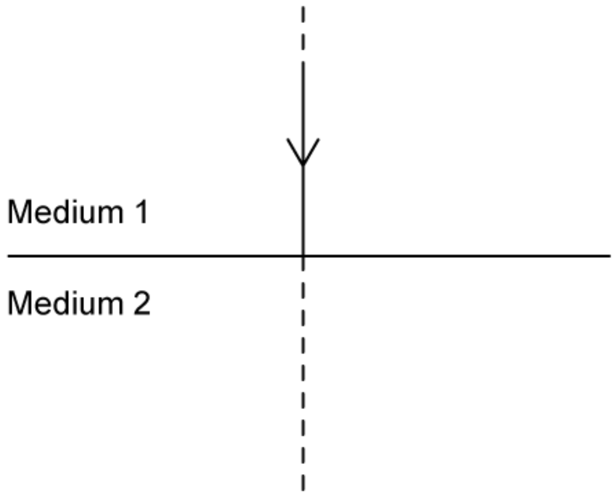
(2 marks)

(b) The following diagram shows an incident ray perpendicular to the boundary between two media.



Complete the ray diagram by drawing the transmitted ray.

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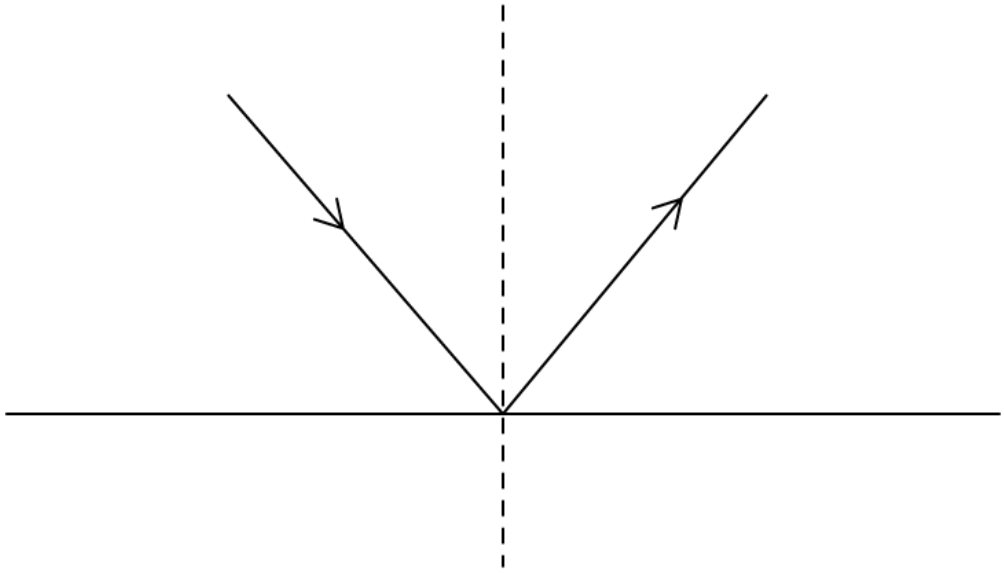
(2 marks)

(c) Ray diagrams can be used to show reflection and refraction. The following diagram shows the reflection of light on a smooth surface.



On the ray diagram label:

(i) The incident ray.

[1]

(ii) The reflected ray.

[1]

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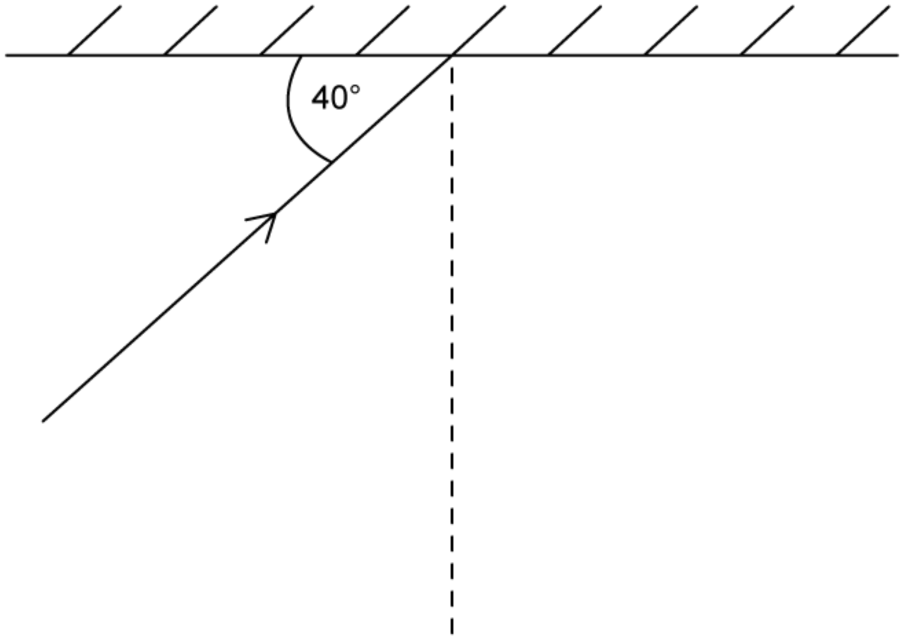
(2 marks)

(d) The ray diagram shows an incident ray on a plane mirror.



Calculate the angle of reflection.

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(3 marks)

13 (a) Refraction occurs when light travels between media with different optical densities.

Describe what happens when light passes from a less dense medium into a more dense medium in terms of:

(i) The relative sizes of the angles of incidence and refraction.

[1]

(ii) The direction of the refracted light ray in relation to the normal.

[1]

....

....

(2 marks)

(b) The refractive index is calculated using the equation:

$$n = \frac{c}{v}$$

Write in the missing information to complete the following table:

Quantity	Symbol	Units
	n	No units
	c	
Speed of light in medium	v	

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....

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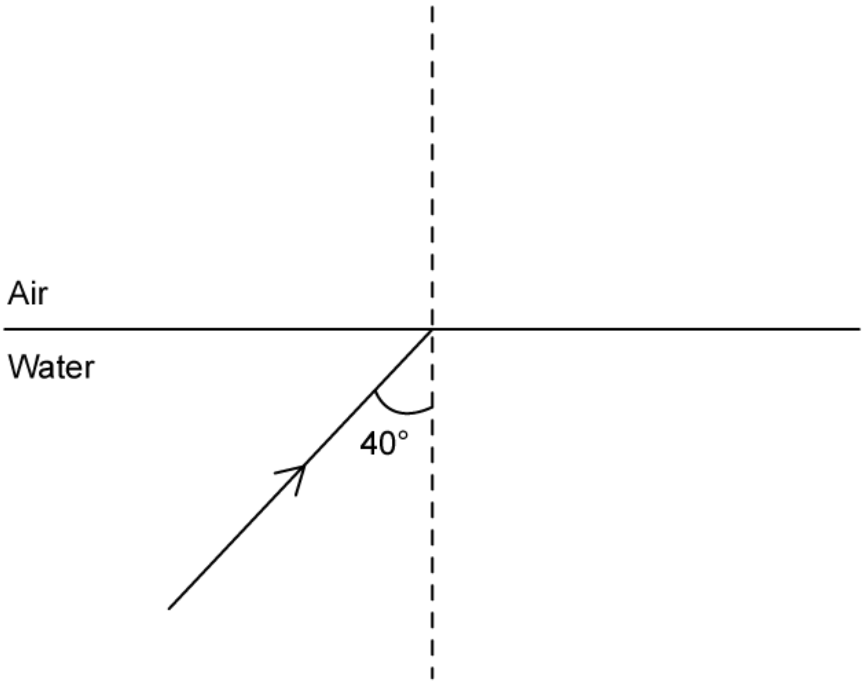
(3 marks)

(c) Define the term critical angle.

....

(1 mark)

(d) Incident light travelling through water approaches the surface of the water and meets the boundary with air. The incident ray has an angle of incidence = 40°.



The refractive index of air is 1.00 and the refractive index of water is 1.33.

Calculate the angle of refraction for the refracted ray.

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....

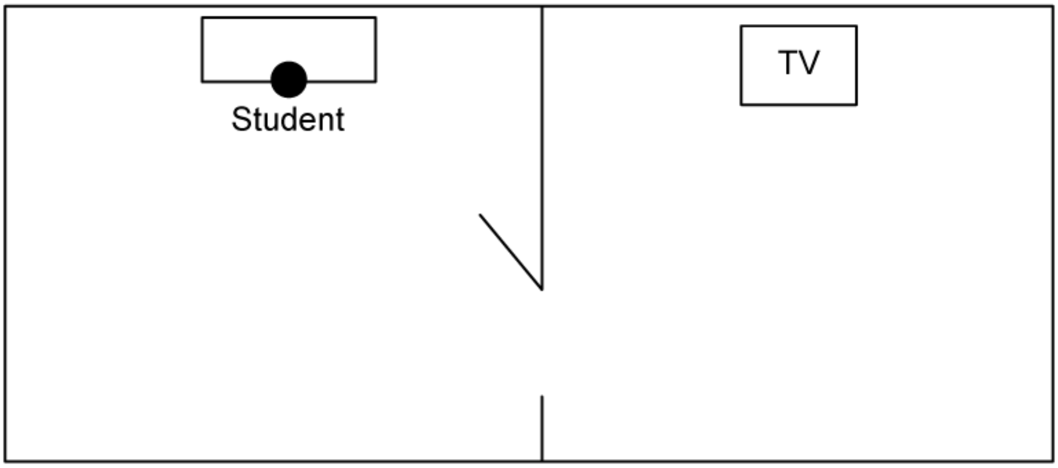
(2 marks)

14 (a) Define diffraction.

....

(1 mark)

(b) The diagram shows a student in a room with an open door and a television in the next room.



The student can hear the sound of the television, but cannot see the picture coming from it.

Complete the following sentences by circling the correct word to explain why this is the case.

Sound waves emitted from the television **diffract / refract** around the opening of the door because the **amplitude / wavelength** is similar in size to the door. The **amplitude / wavelength** of light is much **larger / smaller** than that of the sound waves, so light is not not **diffracted / refracted** around the opening of the door.

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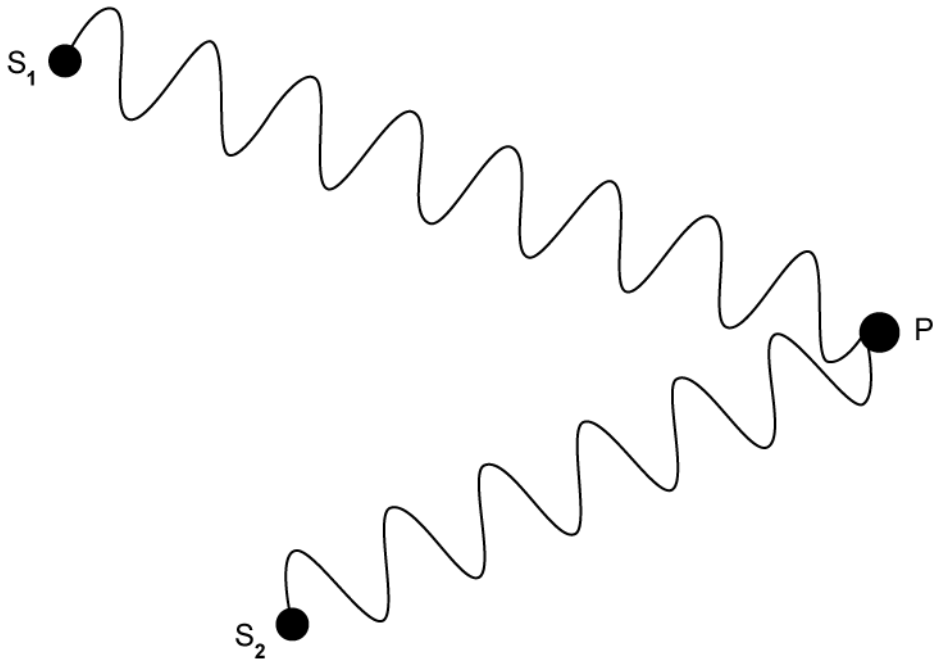
(5 marks)

(c) Define coherence.

(1 mark)

(d) The diagram shows two different waves from sources s_1 and s_2 meeting at point P.



For the waves meeting at point P:

(i) Determine the path difference.

[3]

(ii) State whether the interference will be constructive or destructive.

[1]

(4 marks)

15 (a) Outline the conditions for destructive interference.

....

(1 mark)

(b) Some light can be described as monochromatic.

State what is meant by the term monochromatic.

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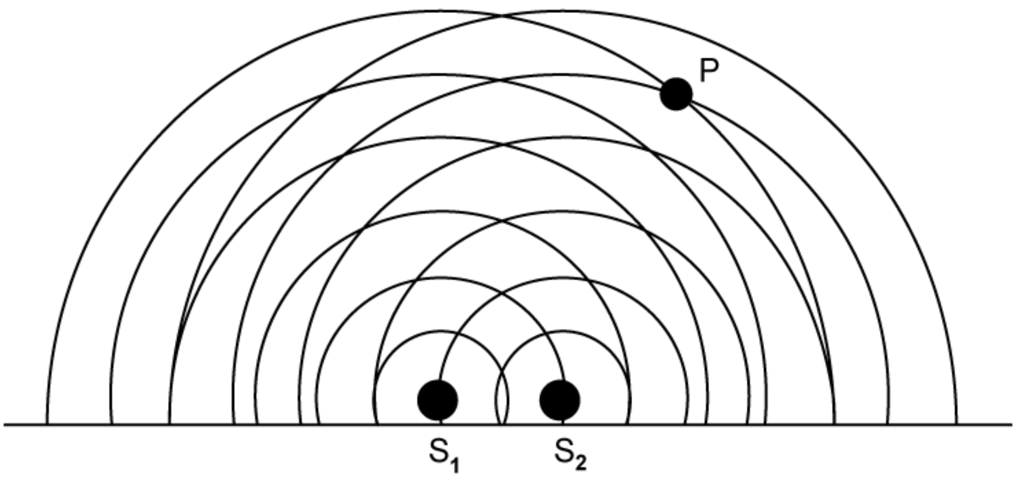
(1 mark)

(c) The diagram shows the wave fronts emitted from two point sources s_1 and s_2.



The waves meet at point P.

(i) By considering the number of waves, determine the path difference.

[3]

(ii) State whether constructive or destructive interference would occur at point P.

[1]

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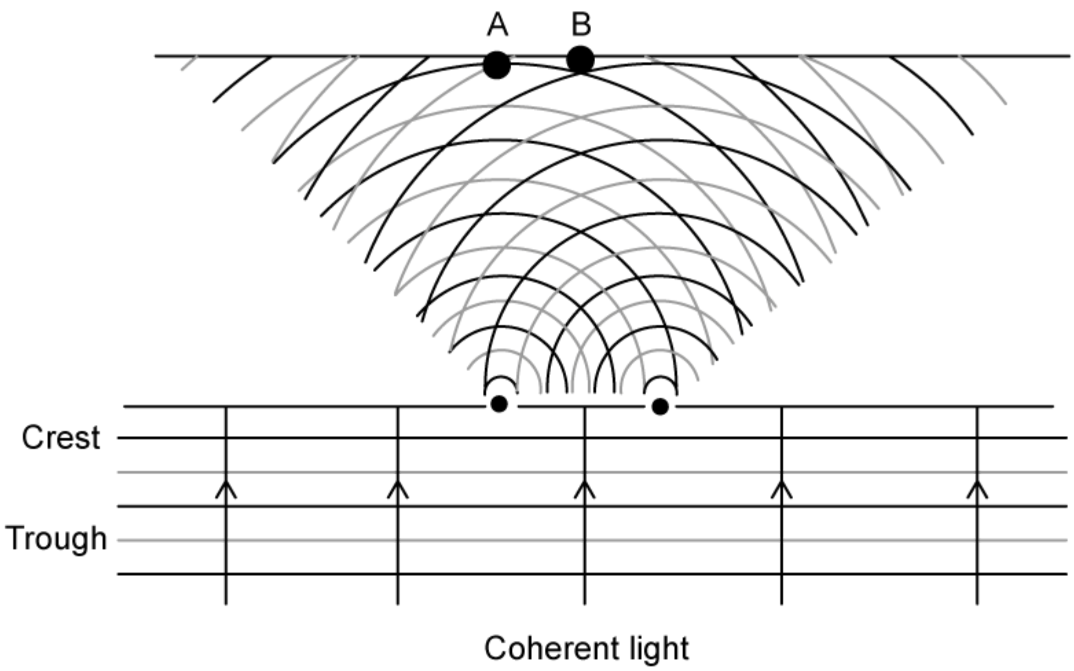
(4 marks)

(d) The diagram shows two sources of coherent light producing a double-slit interference pattern.



State whether the interference is constructive or destructive at point:

(i) A.

[1]

(ii) B.

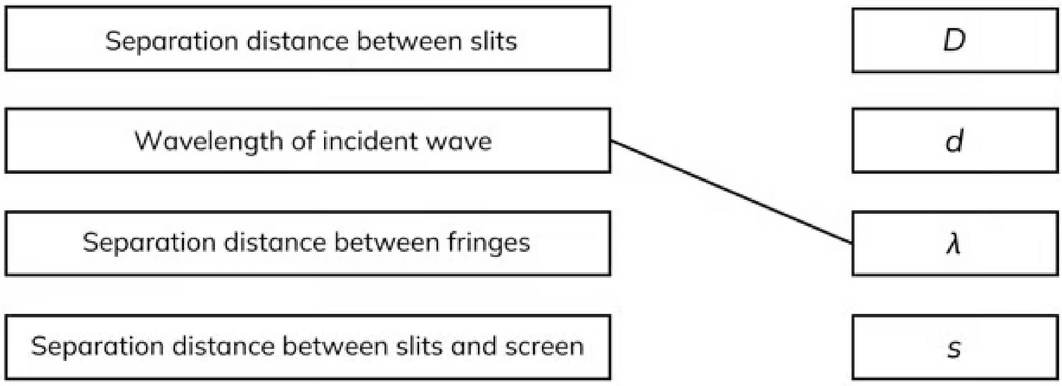
[1]

(2 marks)

16 (a) The distance between the bright fringes in a double-slit interference pattern can be determined by the double-slit equation

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

Draw a line to match the quantity to the correct symbol.



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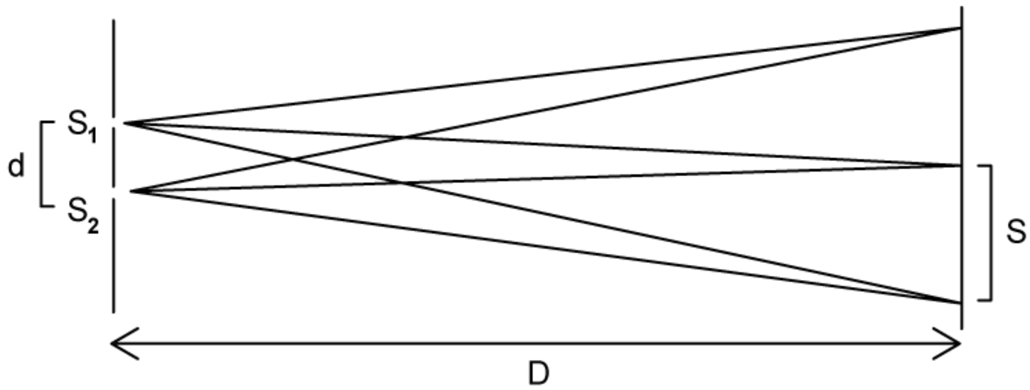
(3 marks)

(b) Red laser light is used to form a double-slit interference pattern on a screen.



The distance between the bright fringes depends on the wavelength of the incident light.

Outline how the interference pattern would be affected if blue laser light were used instead.

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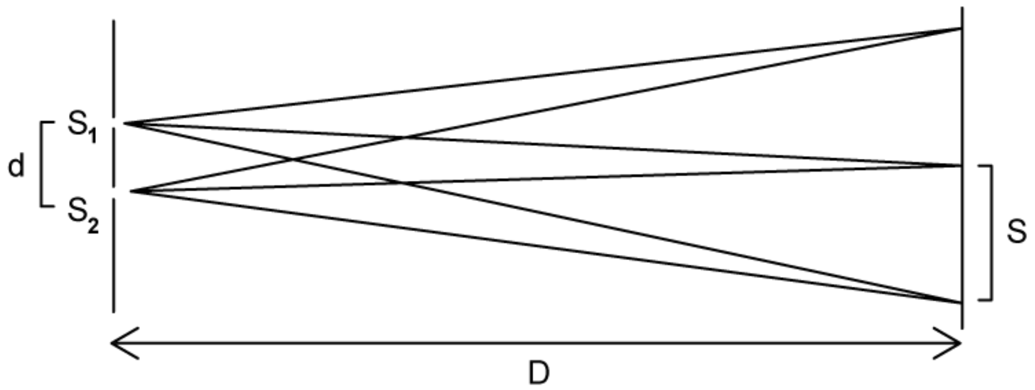
(2 marks)

(c) Red laser light of wavelength λ = 650 nm is used to form a double-slit interference pattern on the screen as shown.



The separation distance of the slits d = 0.2 mm, and the distance between the slits and the screen D = 1.2 m.

Calculate the separation distance between the fringes on the screen *s.*

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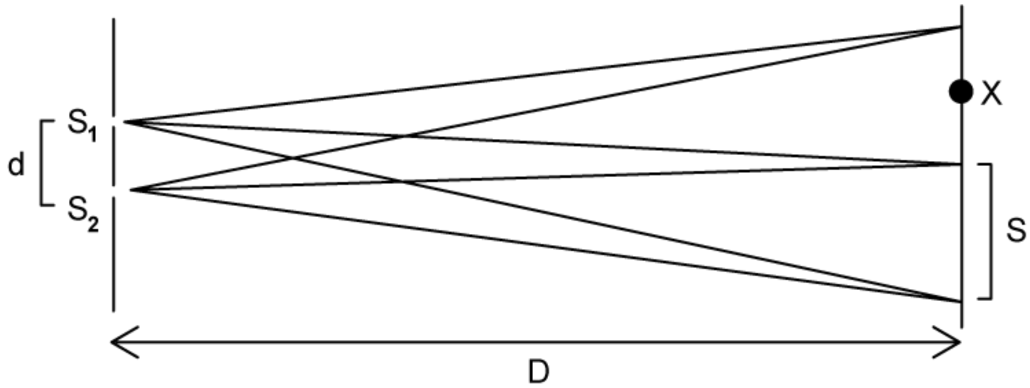
(4 marks)

(d) For the interference pattern shown in part (c):



Explain why there is no bright fringe at point X.

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....

(2 marks)

Medium Questions

1 (a) The formula for the position of the first minimum of the diffraction pattern produced by a single slit is given by:

$$\theta = \frac{\lambda}{b}$$

Using the conditions for interference, derive this formula.

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....

(4 marks)

(b) The frequency of monochromatic light passing through a slit is 2.44×10^{14} Hz. The screen is located 3.75 m from the single slit. The distance on the screen from the central maximum to the first minimum is 0.25 cm.

Find the slit width.

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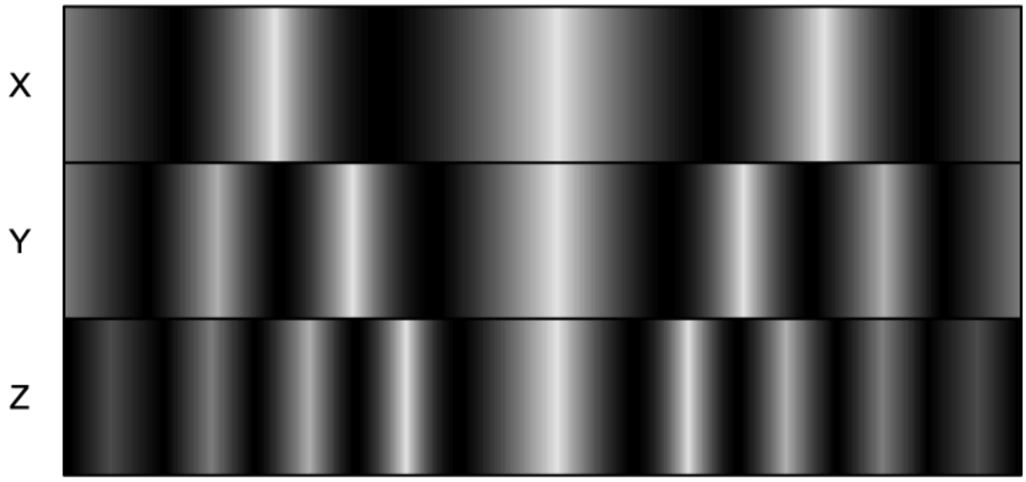
(3 marks)

(c) Three diffraction patterns, x, y and z, are produced from three wavelengths of light, λ, 5λ and 10λ, passing through a slit of fixed width b.



(i) State the wavelength of light that produced each diffraction pattern, x, y and z.

[2]

(ii) Explain which pattern has the highest intensity at the central maximum and state how to increase the intensity at the central maximum.

[2]

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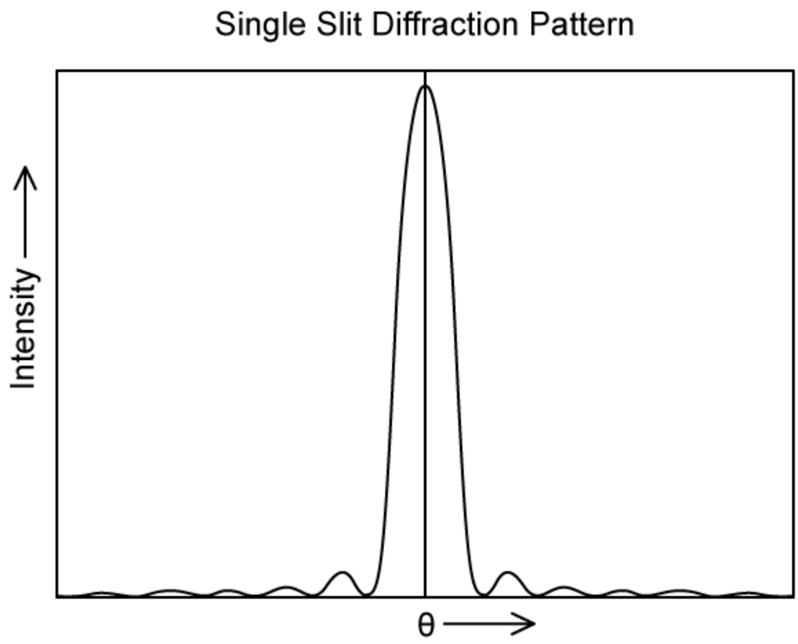
(4 marks)

(d) The graph below shows the variation of light intensity, I with angular displacement θ on a screen placed far away from a narrow slit.

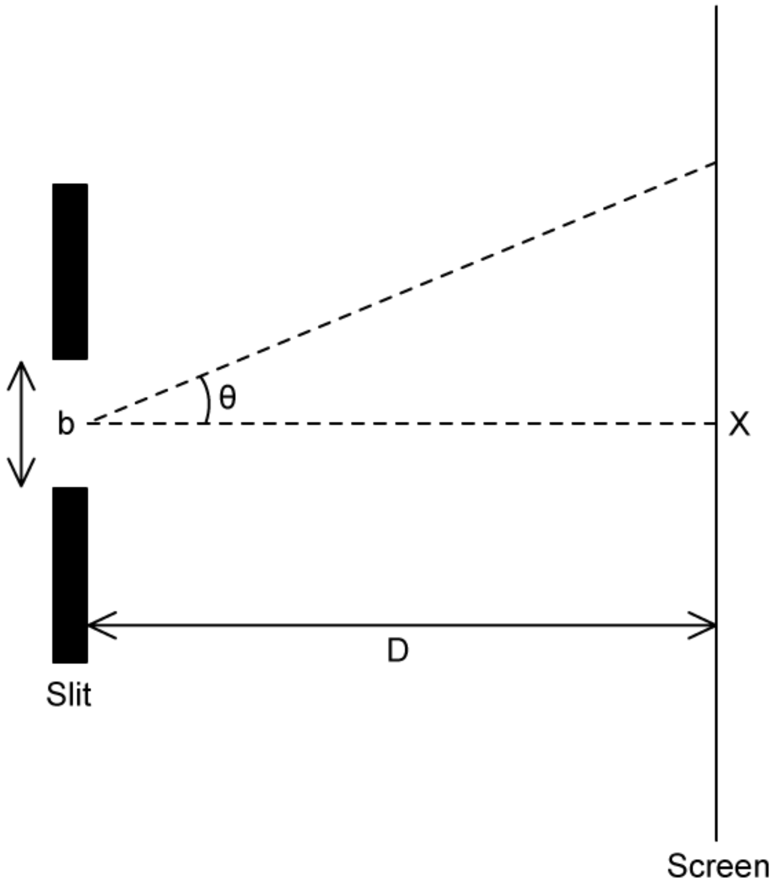


Draw the variation of light intensity, *I* with angular displacement θ on a screen when the narrow slit is been made even narrower.

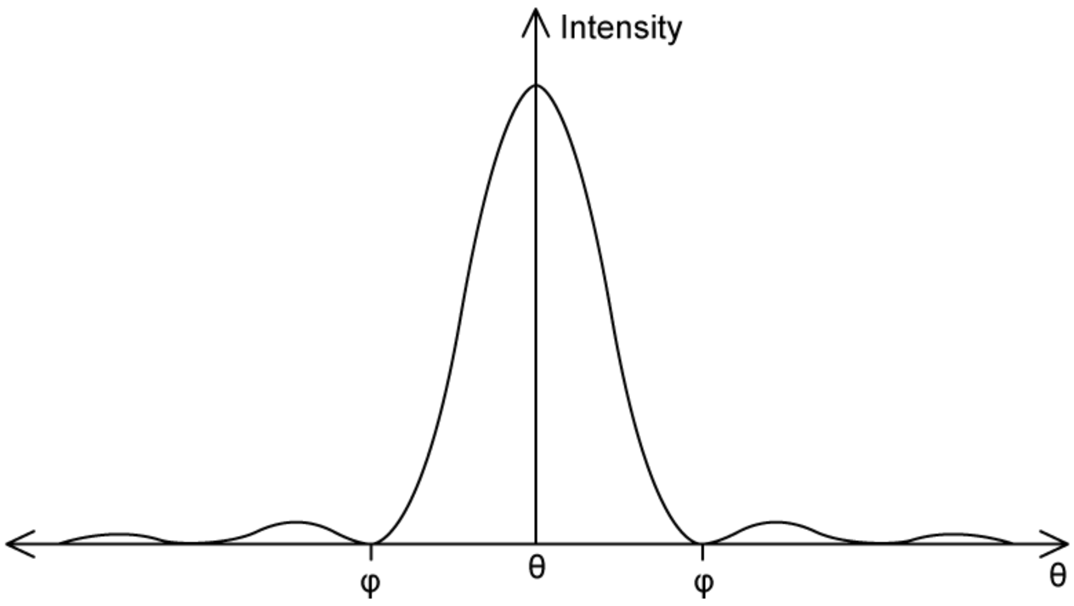
(2 marks)

2 (a) Plane wavefronts of monochromatic light of wavelength λ are incident on a rectangular slit of width b. The light is brought to a focus after passing through the slit on a screen at a distance D from the slit as shown in the diagram below.

The width of the slit is comparable to the wavelength of the light and $b \ll D$. The point X on the screen is opposite the centre of the slit.



The variation of the intensity incident on the screen with angle θ is shown on the graph below.



Explain the shape of the intensity distribution in terms of the conditions for interference.

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(3 marks)

(b) The angular half-width of the central maximum for this intensity distribution is given by the expression $\varphi = \frac{\lambda}{b}$ where $\theta = \varphi$.

Derive an expression for the half-width, d, of the central maximum using the terms, D, λ and b.

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(3 marks)

(c) In a single-slit diffraction experiment, the slit width is 0.030 mm and the wavelength of the light incident on the slit is 525 nm.

Calculate the angle of diffraction for the second maxima.

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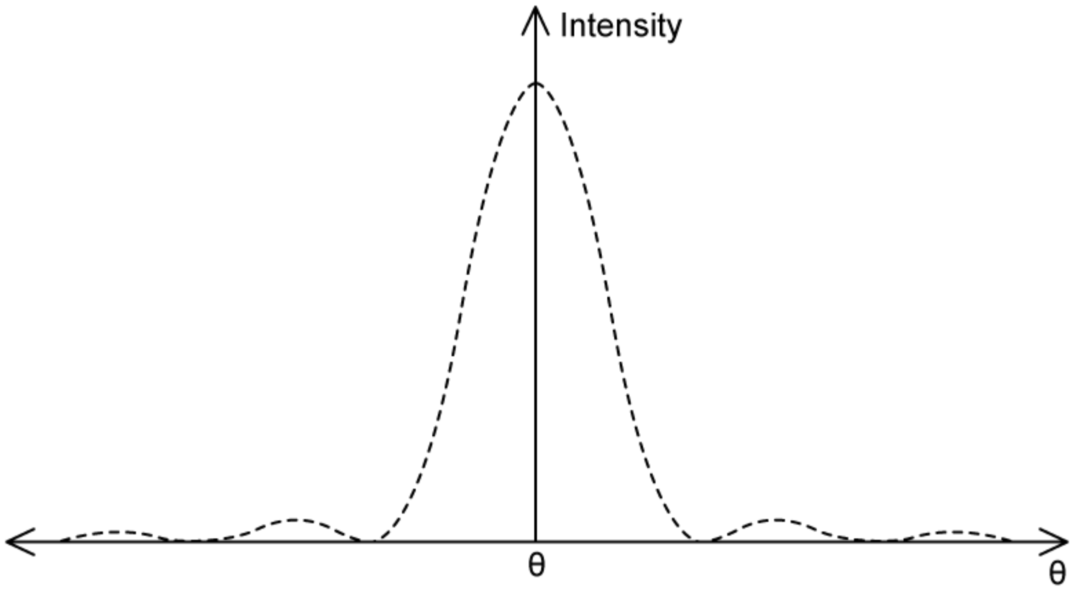
(2 marks)

(d) The single slit of width *b* is replaced by three rectangular slits, also of width *b*. The intensity distribution of a single slit is shown by the dotted line.



Draw a sketch within the central maxima of the single slit of the new intensity distribution on the screen.

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(3 marks)

3 (a) An experiment is set up where white light is incident on a single slit.

The white light illuminates the slit. The first diffraction minimum for a wavelength of 630 nm is observed at 12°.

(i) Calculate the slit width.

[1]

(ii) Outline the effect on the diffraction angle if the slit width was made narrower.

[1]

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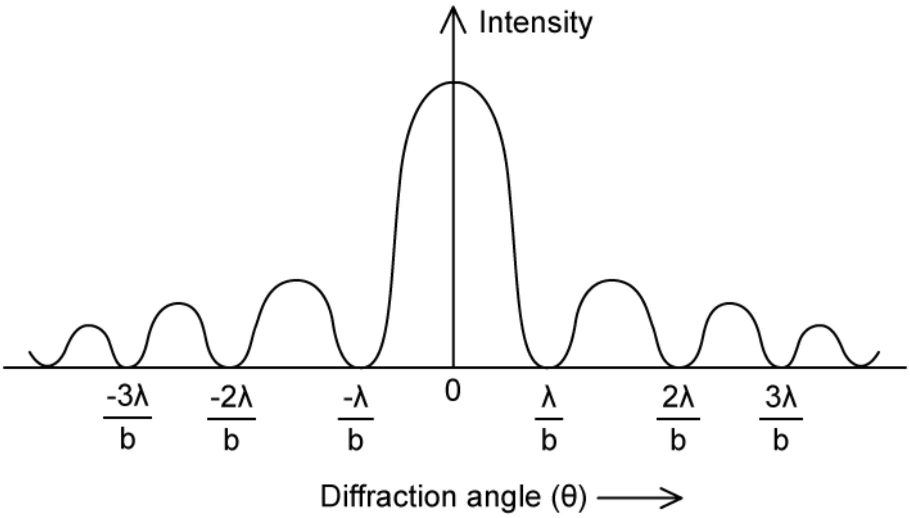
....

(2 marks)

(b) (i) On the single-slit intensity graph below, identify the first secondary maximum and the second diffraction minimum.

[1]



(ii) Determine the wavelength of light for which the first secondary maximum occurs at an angle of 12°.

[2]

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(3 marks)

(c) Explain why the central maximum is white but the first secondary maximum at 12° is coloured.

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(3 marks)

(d) Explain the pattern of the colours seen on the screen between 12° and the next minima.

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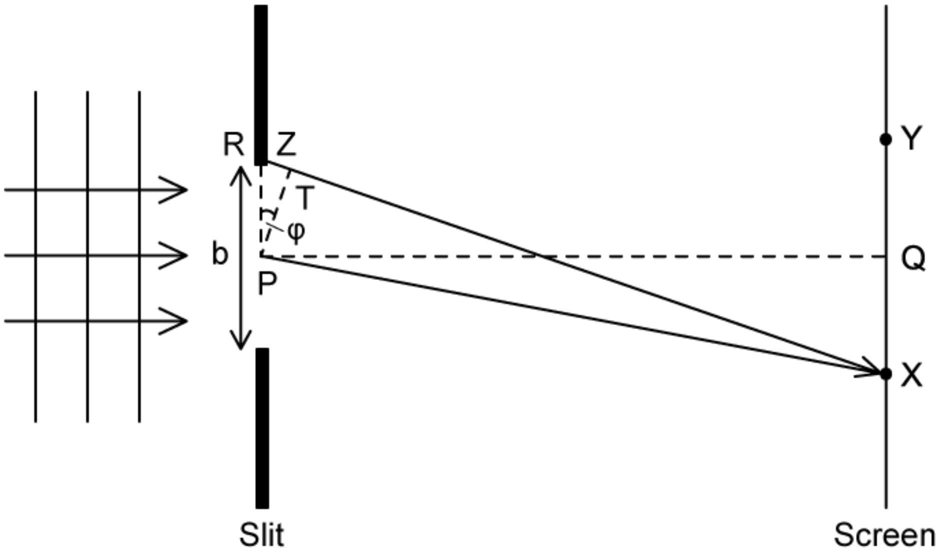
(3 marks)

4 (a) A rectangular slit has width *b* and is comparable to the wavelength λ of plane wavefronts of monochromatic light incident upon it. After passing through the slit, the light is brought to a focus on a screen.



The diagram shows a line normal to the plane of the slit, drawn from the centre of the slit to the screen is labelled PQ. The points X and Y are the first points of minimum intensity as measured from point Q.

The diagram also shows two rays of light incident on the screen at point X. Ray RX leaves one edge of the slit and ray PX leaves the centre of the slit. The angle φ is small.

On the diagram, label two angles of diffraction.

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(2 marks)

(b) Derive an expression, in terms of λ, for the path difference RT between the rays RX and RT.

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(4 marks)

(c) Describe the changes in the experimental setup that would decrease the width of the central bright maximum.

(4 marks)

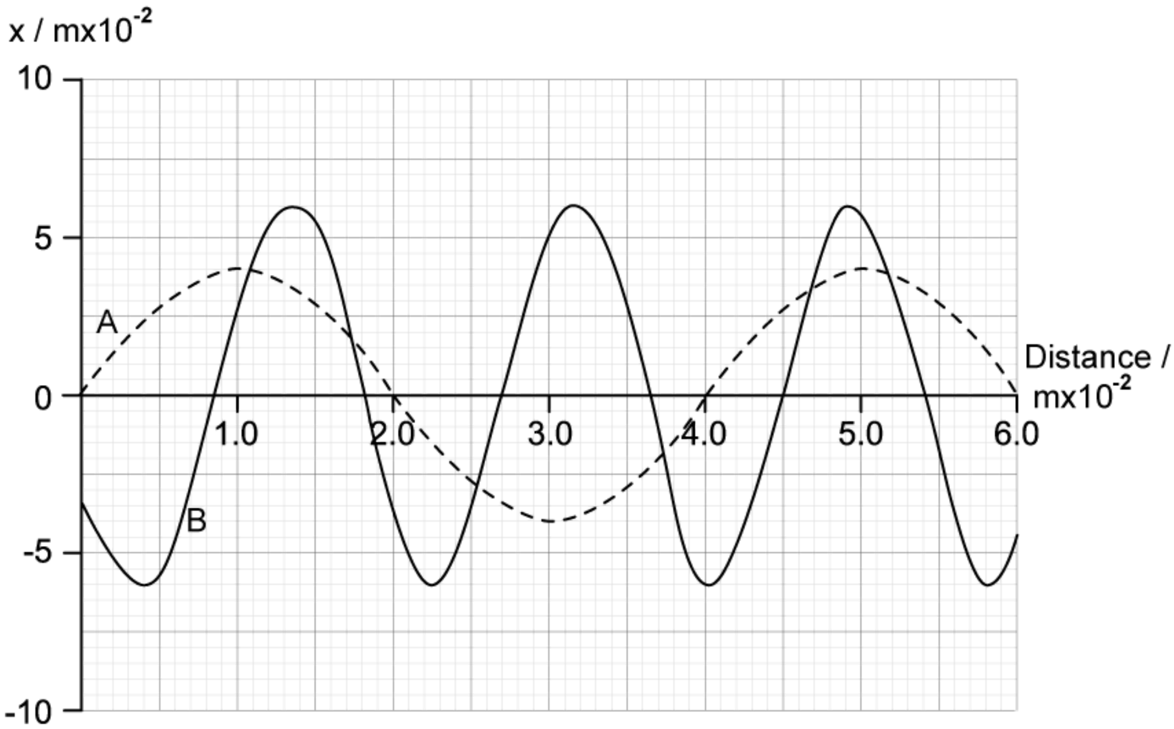
(d) In a certain demonstration of single-slit diffraction λ = 400 nm, b = 0.12 mm, and the screen is a long way from the slit.

Calculate the angular width of the central maximum of the diffraction pattern on the screen.

(2 marks)

5 (a) A large water tank is set up so that a wave can be generated at each end of the tank. The two waves, A and B, travel towards each other at the same speed.

The graph shows the variation of displacement of the water surface with distance travelled at a particular instant.



Deduce how many times greater the amplitude of B is to the amplitude of A.

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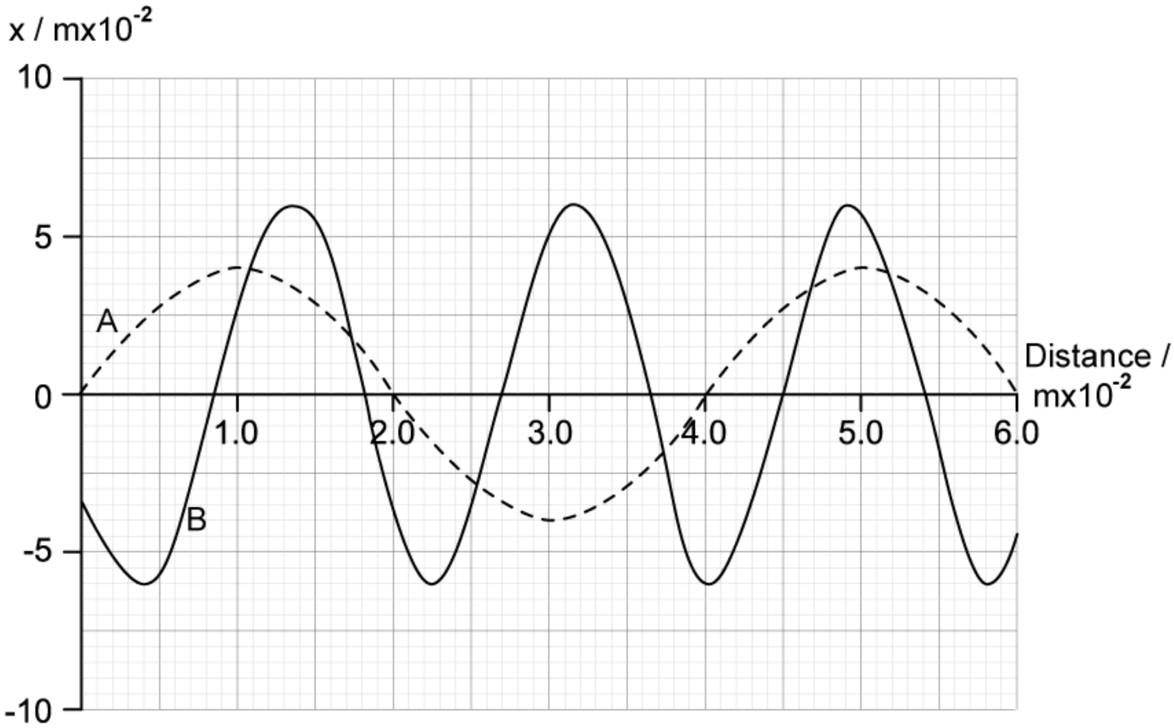
....

(2 marks)

(b) Wave A has a frequency of 9.0 Hz.



(i) Calculate the velocity of wave A

[2]

(ii) Determine the frequency of wave B

[2]

(4 marks)

(c) Sketch a graph to represent the wave which would result from the superposition of wave A and wave B.

(4 marks)

6 (a) Superposition occurs when two or more waves interfere with each other.

(i) Explain the conditions required for a consistent stationary interference pattern to form during superposition.

[2]

(ii) Sketch a diagram to support your answer to part (i).

[2]

(4 marks)

(b) Superposition is often demonstrated using water waves which are transverse and clearly show increases and decreases in amplitude.

Describe how sound waves can also undergo superposition.

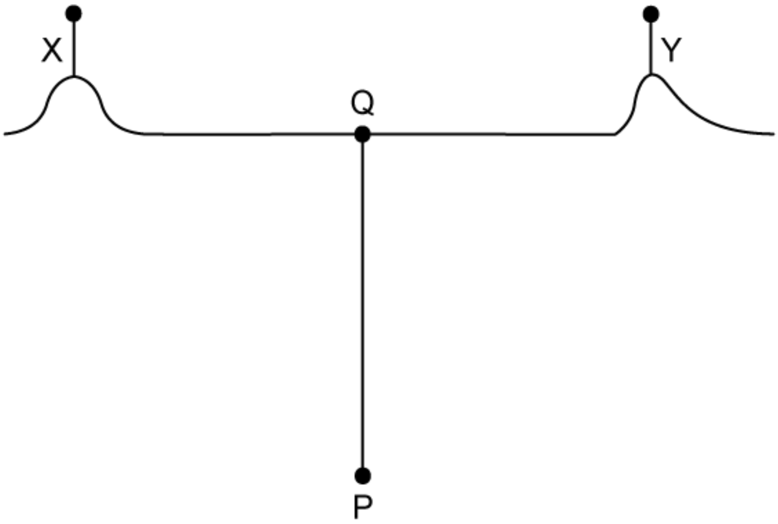
(3 marks)

(c) Two microwave transmitters are placed 15 cm apart and connected to the same source. A receiver is placed 70 cm away and moved along a line parallel to the transmitters. The receiver detects and alternating pattern of maxima and minima.

Explain how the maxima and minima are formed.

(3 marks)

7 (a) A group of hikers are exactly equidistant between two radio transmitters, X and Y. The transmitters are set to an operating wavelength of 200 m and have the same power outputs.



The hikers at point P receive a signal with zero amplitude. Outline what information about the signal you can assume from this.

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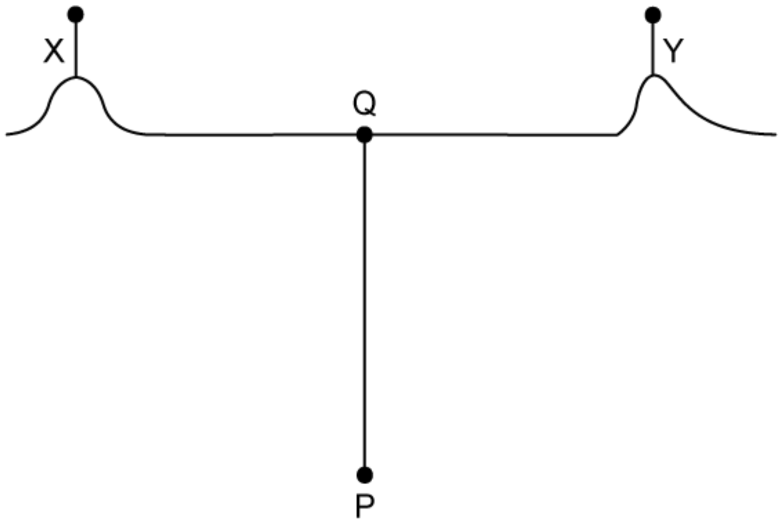
(3 marks)

(b) The hikers walk towards point Q on the line shown and continue to receive a signal of zero amplitude.

Once at Q they turn and walk towards Y, continuing until they receive a signal with amplitude double that emitted from either transmitter.



(i) Explain why there is no increase in amplitude detected on the walk from P to Q

[2]

(ii) Calculate the distance they walked along the line from Q to Y

[2]

(4 marks)

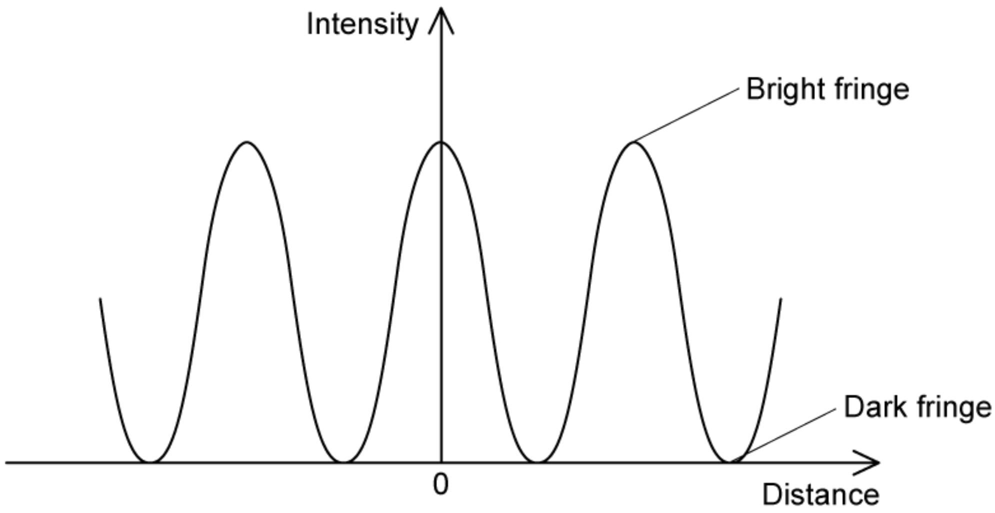
(c) The hikers continue moving from Q towards the transmitter at Y where the distance QY is 20 km. The signal continues to rise and fall as they walk.

Calculate how many times they will hear the signal fall in intensity as they walk.

(2 marks)

8 (a) Several students are conducting investigations with Young's Double Slit Experiment.

In the first investigation, monochromatic light passes through a double-slit arrangement. The intensity of the fringes varies with distance from the central fringe. This is observed on a screen, as shown in the diagram below.



The intensity of the monochromatic light passing through one of the slits is reduced.

Explain the effect of this change on the appearance of the dark and bright fringes.

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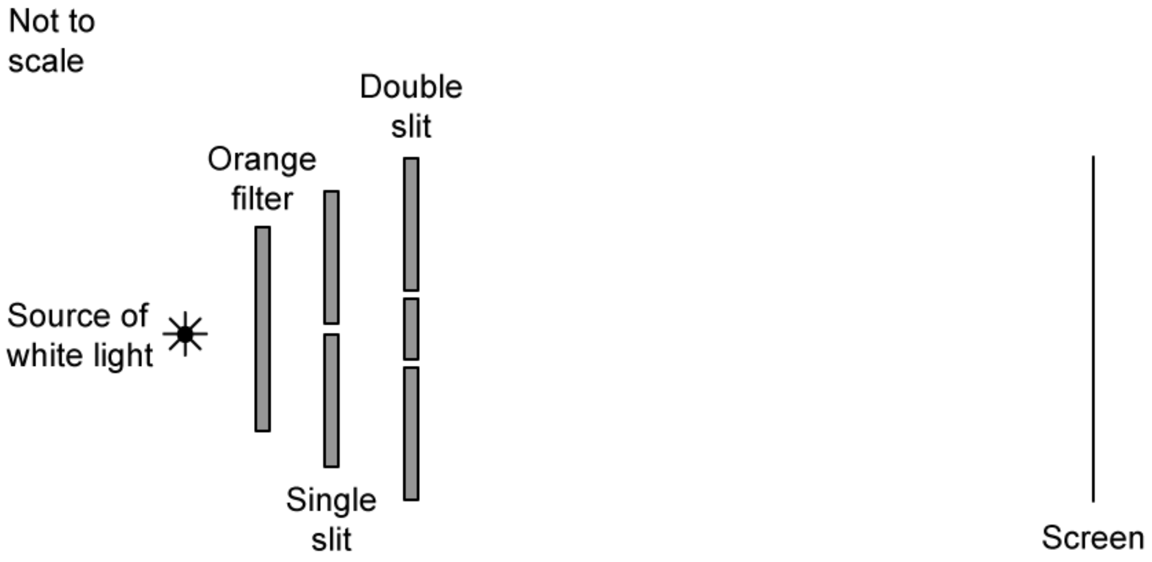
(2 marks)

In investigation, white light is incident on an orange filter, a single slit, and then a double-slit. An interference pattern of light and dark fringes is observed on the screen.

(b)



(i) The orange filter is now replaced by a red filter. State and explain the change in appearance, other than the change in colour, of the fringes on the screen.

[1]

(ii) The red filter is now removed, so there is no filter in front of the white light. State and explain the change in appearance of the central maximum fringe, as well as the fringes away from this central position.

[3]

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(4 marks)

(c) In a third experiment, the white light is replaced by orange light of wavelength 600 nm. The double-slit has a separation of 0.350 mm and the screen is 6.35 m away.

Calculate the distance between the central and first maximum as seen on the screen.

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(2 marks)

(d) The light source is now changed to a blue LED of wavelength 450 nm.

Explain the features of the interference pattern that will now be observed on the screen.

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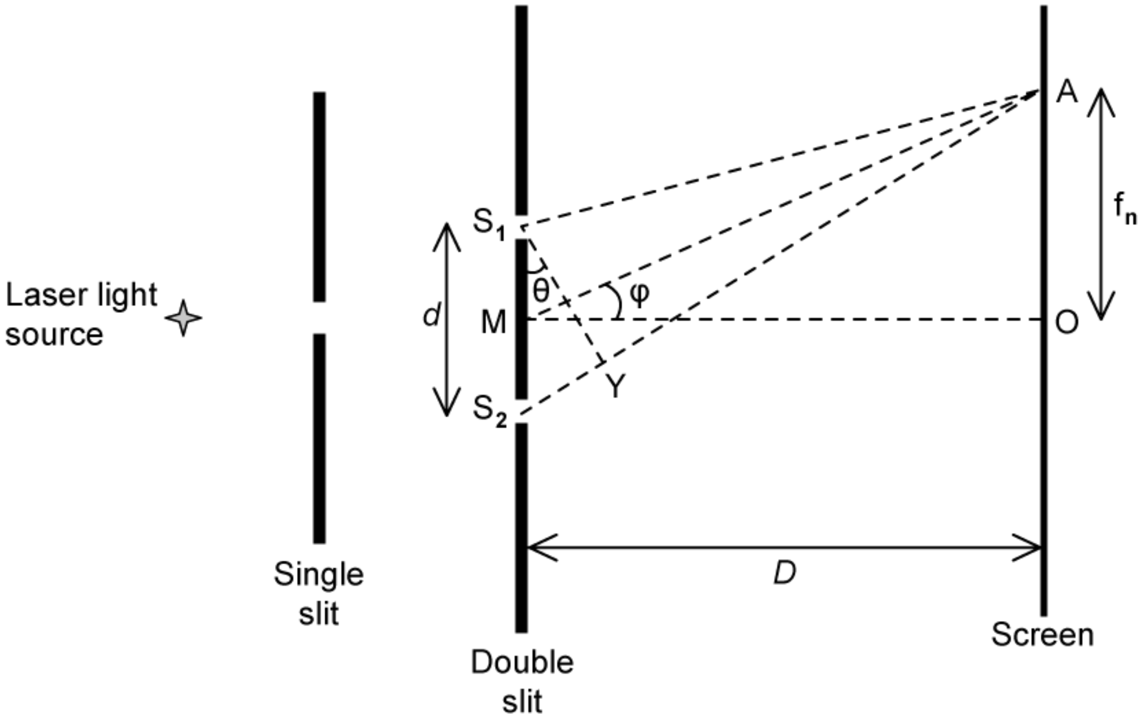
(3 marks)

9 (a) The diagram below shows an arrangement for observing the interference pattern produced by laser light passing through two narrow slits S_1 and S_2.



The distance S_1S_2 is d, and the distance between the double slit and the screen is D where $D \gg d$, so angles θ and ϕ are small. M is the midpoint of S_1S_2 and it is observed that there is a bright fringe at point A on the screen, a distance f_n from point O on the screen. Light from S_1 travels a distance S_2Y further to point A than light from S_1.

The wavelength of light from the laser is 650 nm and the angular separation of the bright fringes on the screen is 5.00×10^{-4} rad. Calculate the distance between the two slits.

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(3 marks)

(b) A bright fringe is observed at A.

(i) Explain the conditions required in the paths of the rays coming from S_1 and S_2 to obtain this bright fringe.

[2]

(ii) State an equation in terms of wavelength for the distance S_2Y.

[1]

(3 marks)

(c) Deduce expressions for the following angles in the double-slit arrangement shown in part a:

(i) θ in terms of S_2Y and d

[2]

(ii) ϕ in terms of D and f_n

[2]

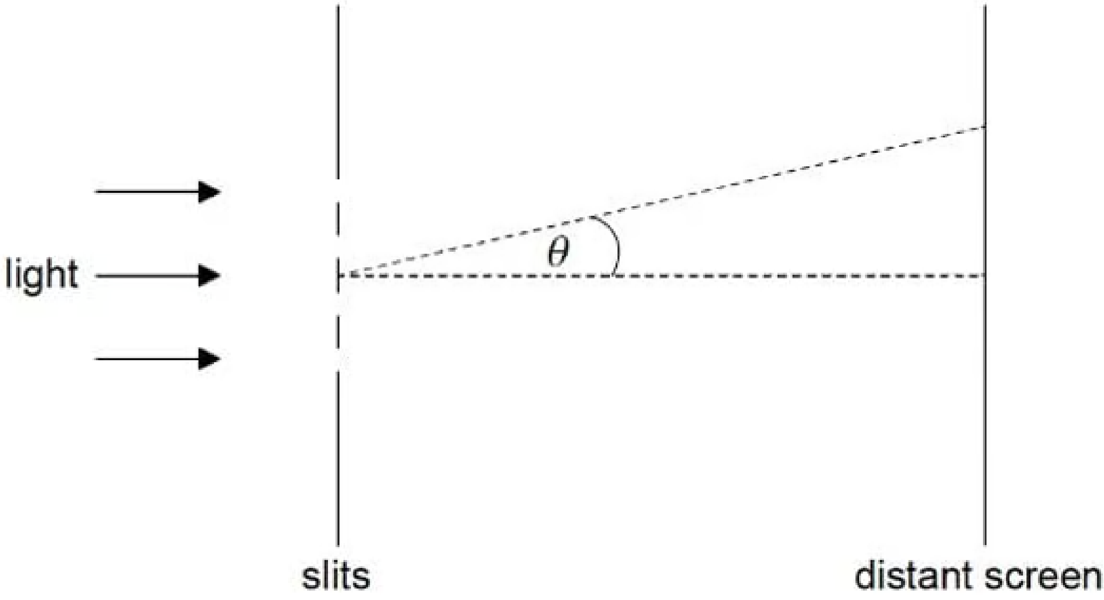
(4 marks)

(d) The separation of the slits S_1 and S_2 is 1.30 mm. The distance MO is 1.40 m. The distance f_n is the distance of the ninth bright fringe from O and the angle θ is 3.70×10^{-3} radians.

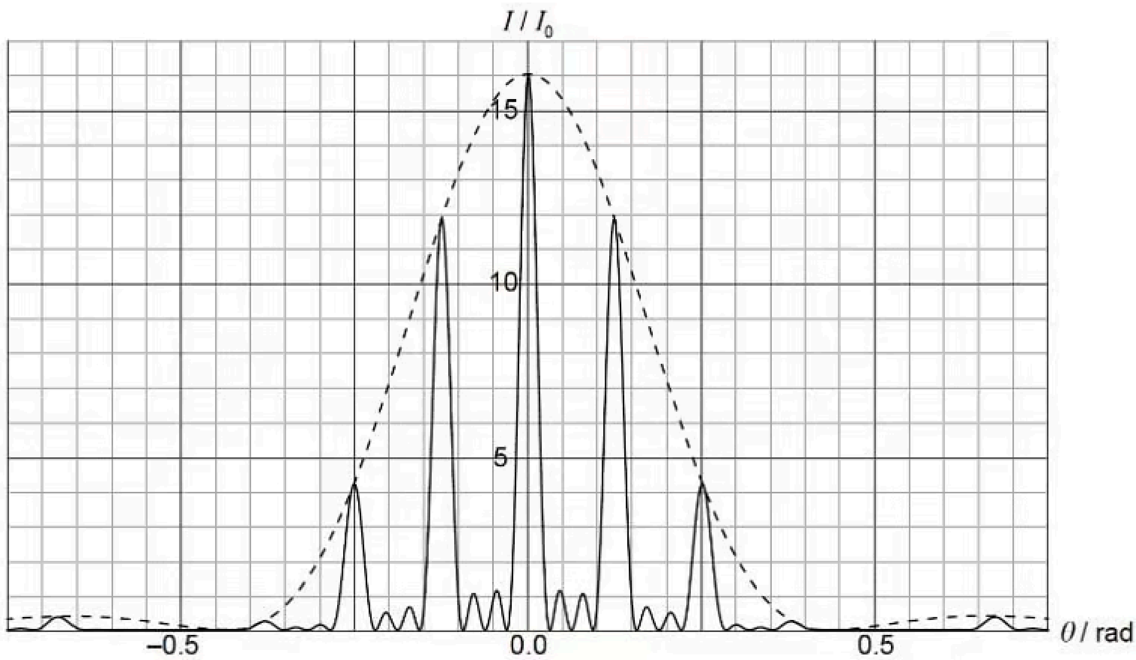
Calculate the wavelength of the laser light.

(2 marks)

10 (a) Monochromatic light is incident normally on four, thin, parallel, rectangular slits.



The graph shows the variation with diffraction angle θ of the intensity of light I on a distant screen.



I_0 is the intensity of the light in the middle of the screen from one slit. Intensity I is directly proportional to the square of amplitude A.

State the value of the light intensity in terms of I_0 when $\theta = 0$ and explain where this value comes from.

(4 marks)

(b) The width of each slit is 2.0 μm.

Use the graph to estimate the wavelength of the light.

(2 marks)

(c) Use the graph to calculate the number of lines per meter on the diffraction grating.

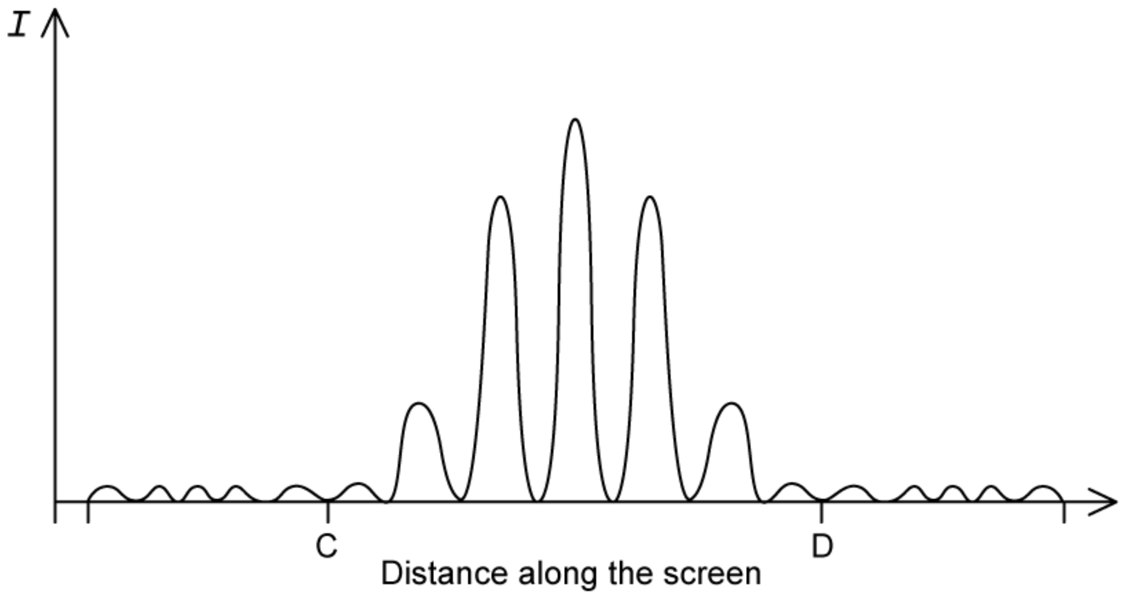
(3 marks)

The four slits are now changed for a grating where the number of slits becomes very large. The separation of the slits and their width stays the same.

(d) State two changes to the graph that will appear as a result of this modification.

(2 marks)

11 (a) Monochromatic light is incident on a double-slit diffraction grating. After passing through the slits the light is brought to a focus on a screen. The intensity distribution of the light on the screen is shown in the diagram below.



The double-slit diffraction grating is now changed to a grating with many narrower slits, the same widths as the slits above.

Sketch the new intensity pattern for the light between points C and D on the screen.

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(3 marks)

(b) The wavelength of the monochromatic light incident on the diffraction grating is 550 nm. The slit spacing of the diffraction grating is 1.34×10^{-6} m.

Calculate the angle between the two second-order maxima.

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(2 marks)

(c) Calculate the total number of orders of diffracted light that can be observed on the screen.

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(2 marks)

(d) Two sources of light now replace the light incident on the diffraction grating. One is the same as the wavelength of the previous source and the other has a slightly longer wavelength.

Compare and contrast the new intensity pattern with the original. Comment on the intensity of the central maxima and the width of all maxima.

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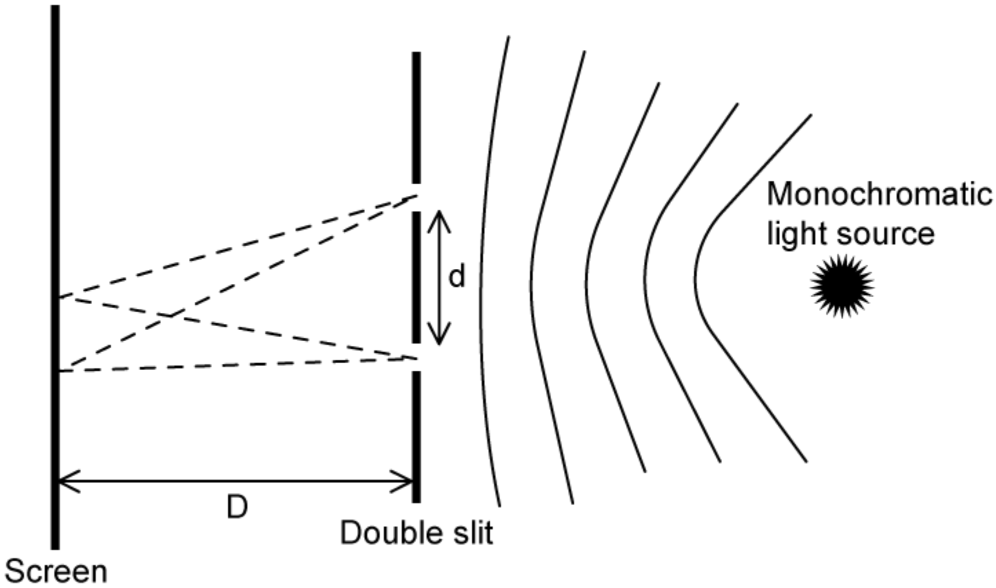
(3 marks)

12 (a) A beam of monochromatic light is incident upon two slits. The distance between the slits is 0.4 mm.



A series of bright and dark fringes appear on the screen. Explain how a bright fringe is formed.

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(2 marks)

(b) Monochromatic light is incident on the double-slits and the distance from the screen is 0.64 m. The distance between the bright fringes is 9.3×10^{-4} m. Determine the wavelength of the incident light.

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(2 marks)

(c) If the wavelength of the incident light is halved and the distance between the slits is doubled, outline the effect on the separation of the fringes of the interference pattern.

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(2 marks)

(d) One of the slits is covered so it emits no light.

Describe how this changes the pattern's appearance and the intensities observed on the screen.

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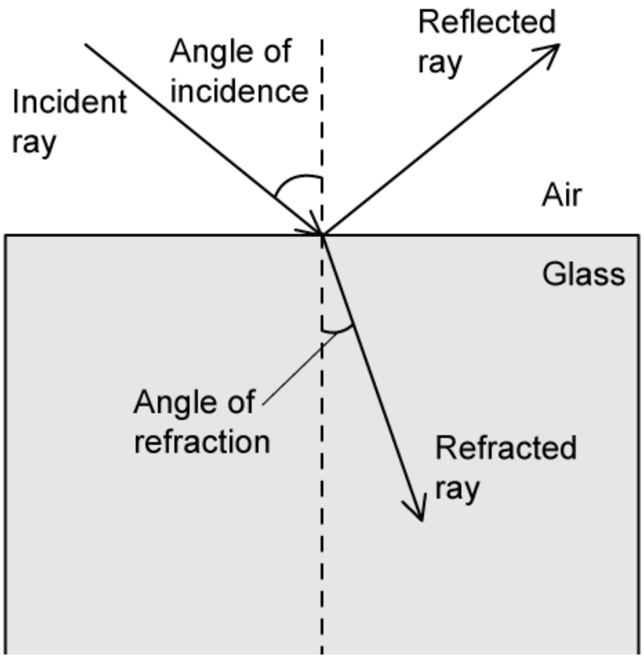
(2 marks)

13 (a) Light is incident upon a piece of glass.



The angle of incidence is less than that of the critical angle. The refractive index of the glass is 1.50.

Explain what is meant by the 'critical angle' and what will occur at angles that are above and below the critical angle.

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(3 marks)

(b) The angle of incidence for this situation is 34°.

Determine the angle of refraction to the nearest degree.

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(2 marks)

(c) The refracted light travels within the glass for 5 m.

Determine the time that the light will take to travel this distance in the glass.

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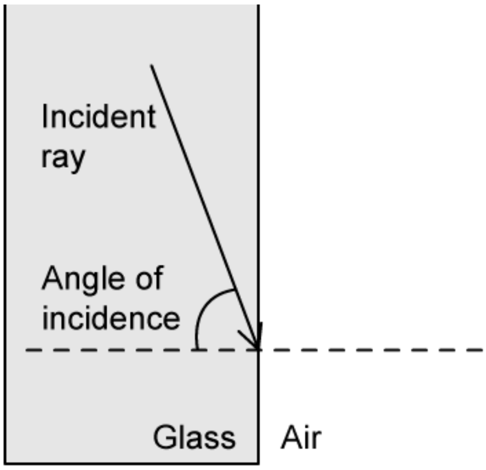
(2 marks)

(d) The light continues within the glass until it strikes the side perpendicular to the original side of entry.



Show that the light will not emerge from the side of the glass.

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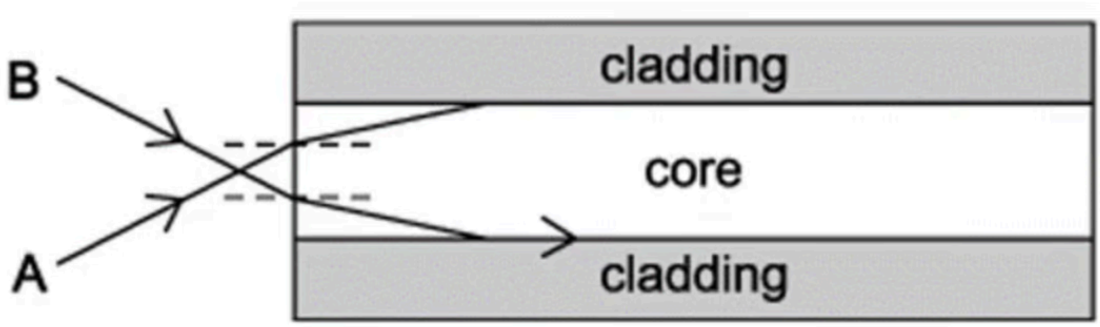
(3 marks)

14 (a) The diagram shows a cross-section through a step-index optical fibre.



Beam A is incident at the end of the optical fibre at an angle of 12.6° to the normal and refracts into the core at 6.89° to the normal.

Calculate the refractive index of the core.

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(2 marks)

(b) Beam A travels through the air-core boundary and experiences total internal reflection.

On the diagram, show the path of this ray down the fibre and label the angle of reflection.

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(2 marks)

(c) Beam **B** is incident at the same end of the fibre. It refracts through the air-core boundary and then refracts again when it hits the core-cladding boundary at an angle of 51.8°, traveling along the boundary.

Calculate the refractive index of the cladding.

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(2 marks)

(d) A different step-index optical fibre is built with the same core as that in part (a) but with a different material used for the cladding.

The speed of light in the new cladding material is 1.54×10^8 m s^{-1}.

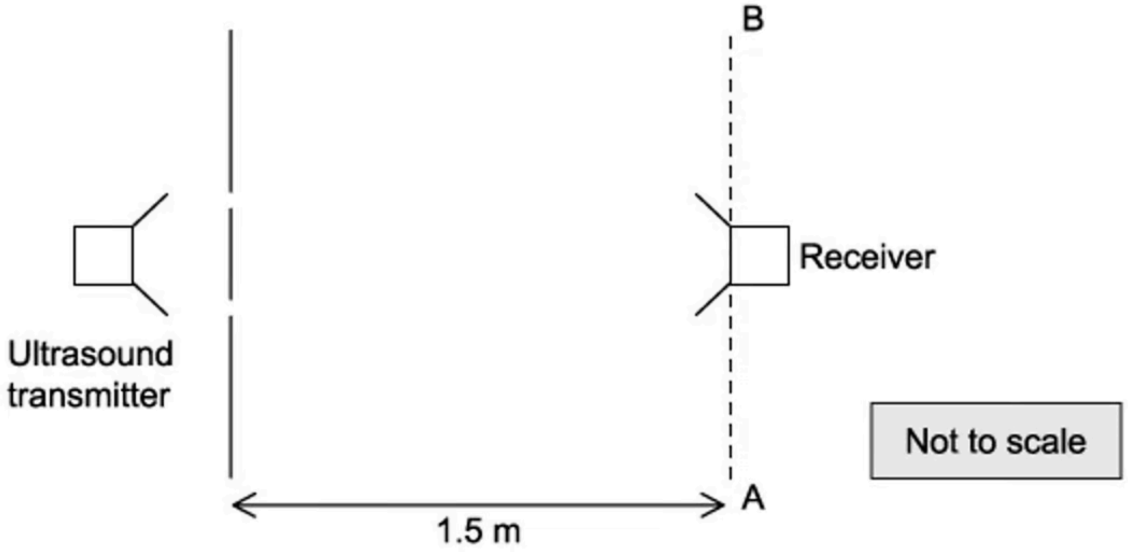
Explain why this new cladding material would not be suitable for sending signals through the step-index optical fibre. Use a calculation to support your answer.

(3 marks)

15 (a) A laboratory ultrasound transmitter emits ultrasonic waves of wavelength 0.7 cm through two slits. A receiver, moving along line AB, parallel to the line of the slits, detects regular rises and falls in the strength of the signal.

A student measures a distance of 0.39 m between the first and the fourth maxima in the signal when the receiver is 1.5 m from the slits.

Figure 1



The ultrasound transmitter is a coherent source.

Explain what is meant by the term coherent source.

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(2 marks)

(b) Explain why the receiver detects regular rises and falls in the strength of the signals as it moves along the line AB.

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(4 marks)

(c) Calculate the distance between the two slits.

(3 marks)

(d) One of the slits is now covered. No other changes are made to the experiment.

State and explain the difference between the observations made as the receiver is moved along AB before and after one of the slits is covered.

(3 marks)

16 (a) White light is passed through a single narrow slit and illuminates a screen.

Describe the patten observed on the screen.

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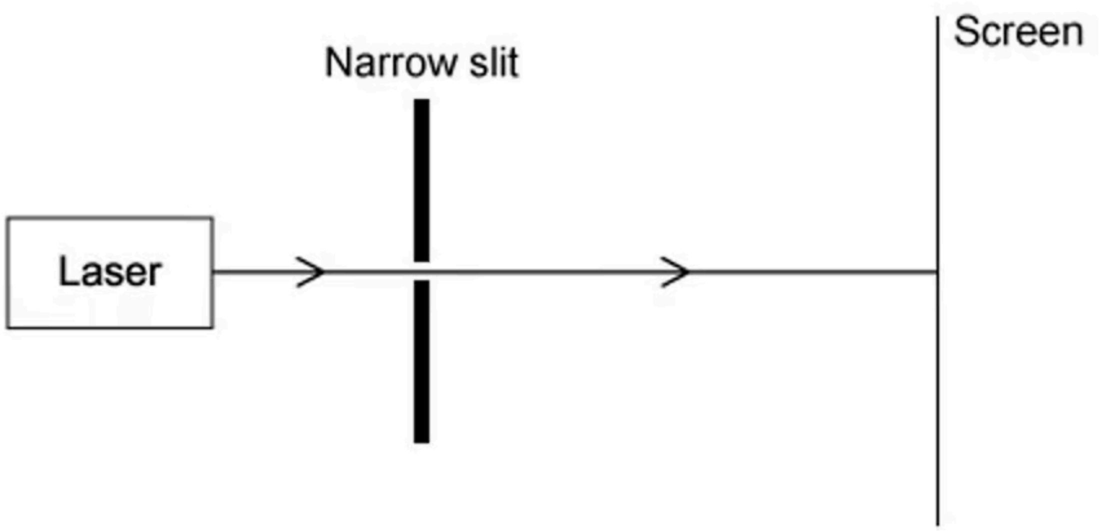
(2 marks)

(b) Blue light from a laser is now passed through a single narrow slit. A pattern of bright and dark regions can be observed on the screen which is placed several meters beyond the slit.



Describe the effect on the diffraction pattern if the width of the narrow slit is decreased.

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(2 marks)

(c) With the original slit width, state and explain the effect on the width of the fringes on the diffraction pattern if the blue light is replaced with a red light of the same intensity.

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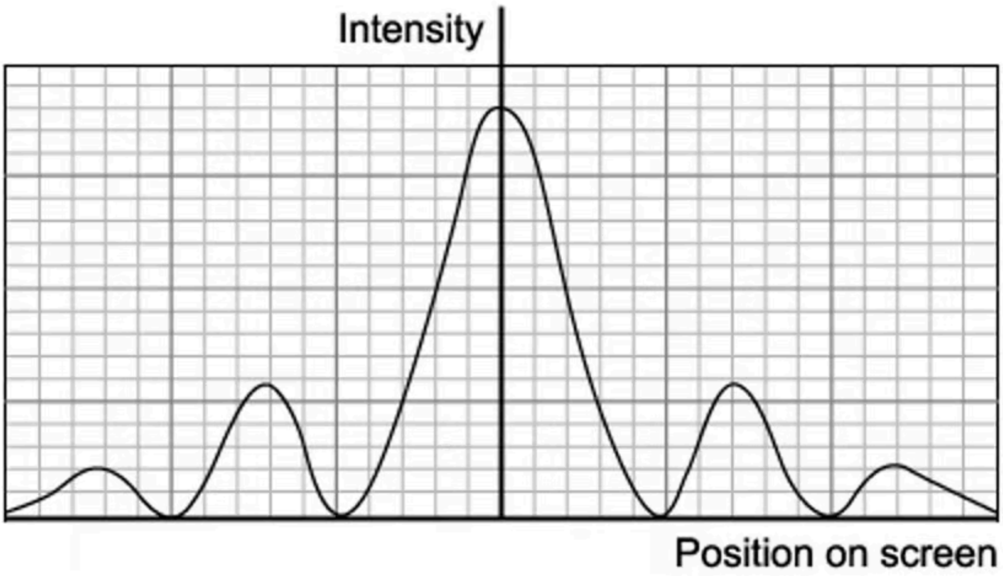
(3 marks)

(d) The intensity graph for the diffracted blue light is shown in the diagram below.

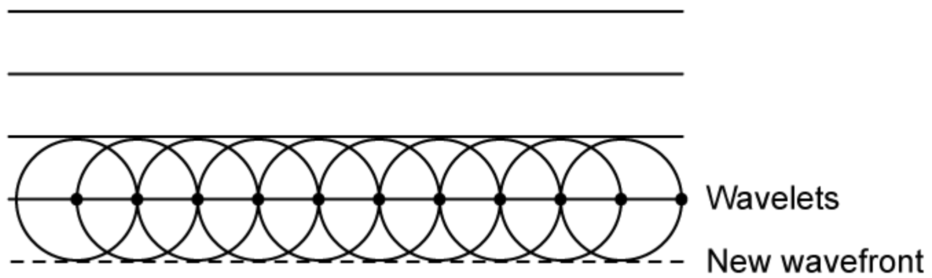


On the axes of the diagram, sketch the intensity graph for the laser emitting red light.

(3 marks)

Hard Questions

1 (a) Huygen's principle states that all points on a wavefront may be regarded as new sources of wavelets that expand in every direction.



Use Huygen's principle to explain single slit diffraction. You may include diagrams in your explanation.

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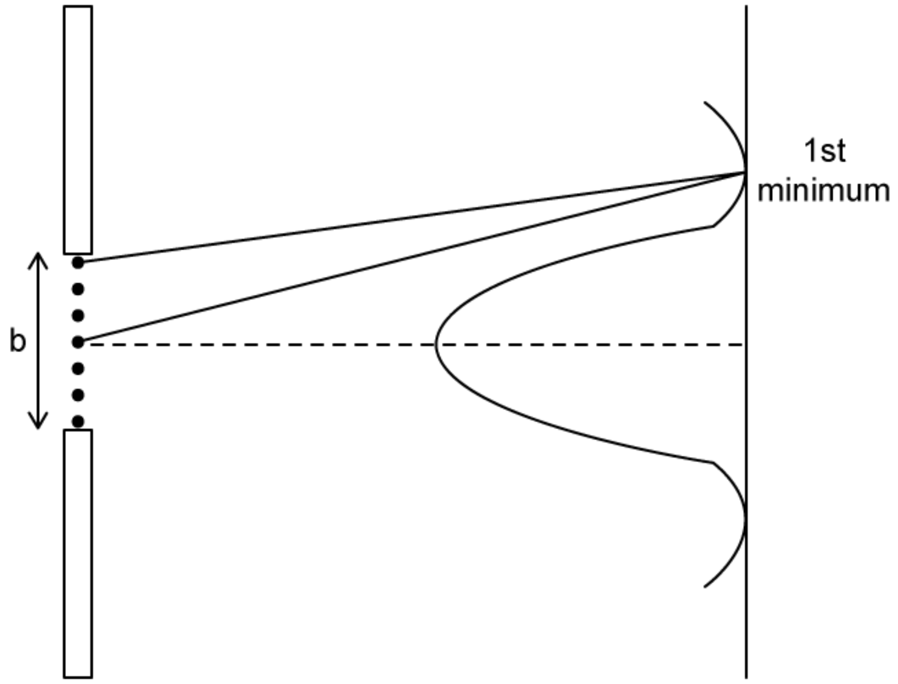
(4 marks)

(b) Huygen's principle explains how destructive interference occurs at the minima of the interference pattern.



The angle of diffraction, θ, is related to the wavelength, λ, of the incident light, and the slit width, b, by the following relationship:

$$\theta = \frac{\lambda}{b}$$

Demonstrate, using geometry, that the minima can be calculated using this equation. You should include a diagram in your answer.

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(6 marks)

(c) Use the information from parts (a) and (b) to prove that, for single-slit diffraction, destructive interference occurs at both odd and even integer multiples of wavelengths, $n\lambda$.

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(5 marks)

2 (a) Some students in a lab are performing a single-slit diffraction investigation. They have a green laser but they do not know the exact wavelength of the light.

Describe which measurements the students can take and how they can use them to calculate the wavelength.

(5 marks)

(b) The students recorded the following information:

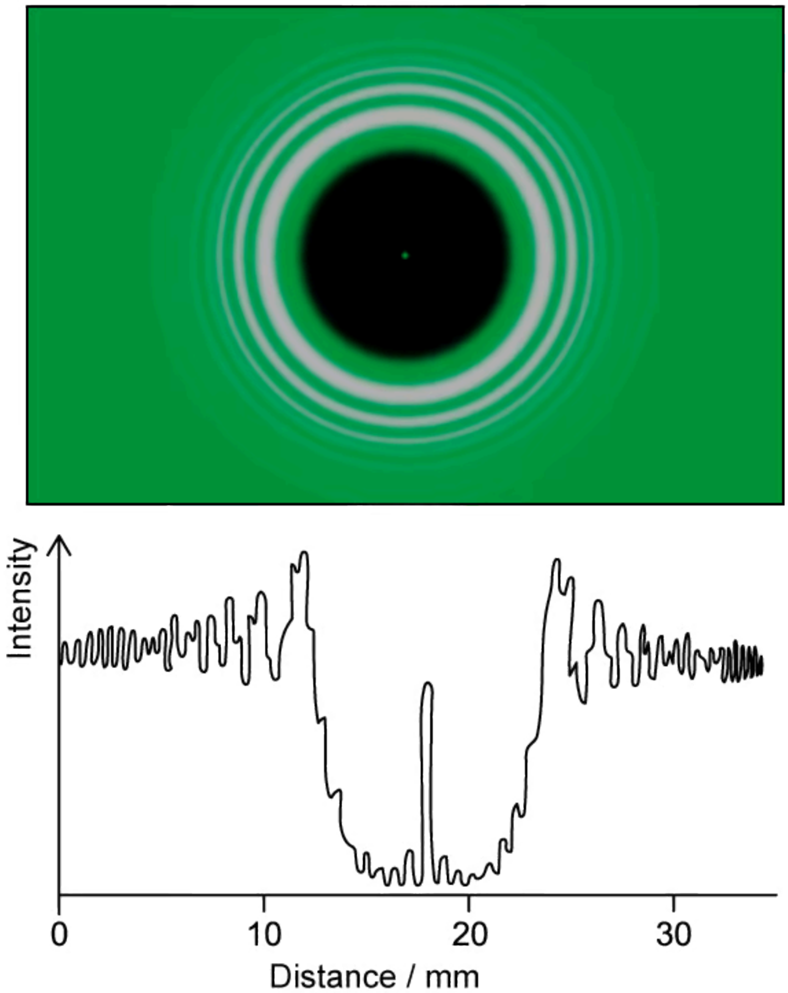
Green laser	Repeat 1	Repeat 2	Repeat 3	Repeat 4	Repeat 5
Distance from slit to screen, *D* / m	3.11	3.12	3.11	3.11	3.12
Slit width, *b* / mm	0.14	0.10	0.71	0.11	0.13
Width of central maximum, *w* / cm	2.8	2.7	2.9	2.9	2.6

Calculate the wavelength of the laser and give its fractional uncertainty.

(5 marks)

3 (a) Single-slit diffraction patterns provide evidence for light as a wave.

The images below show the diffraction of light around a small circular object.



Suggest how the images provide evidence for light as a wave.

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(2 marks)

(b) The image shows a diffraction pattern from a single rectangular slit.

Sketch the diffraction pattern if the slit width was 20% smaller.

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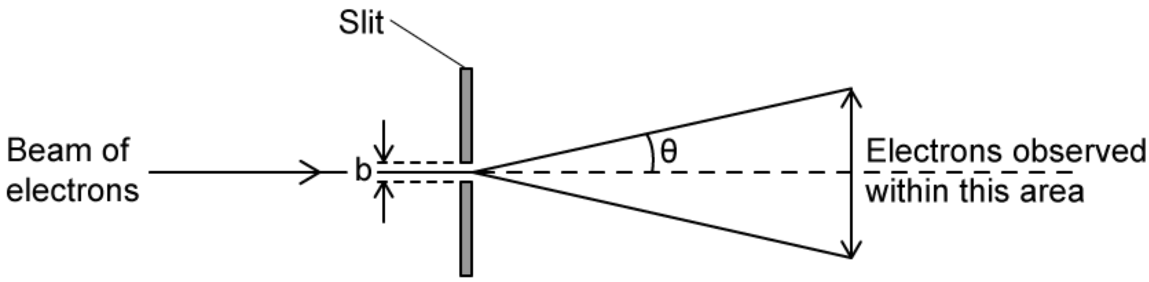
(4 marks)

4 (a) A beam of electrons is incident normally to the plane of a narrow slit of width *b*. The beam of electrons can be observed to diffract over an angular area of 2θ.



The uncertainty in the position, Δx, and momentum, Δp, of an electron in the beam can be described by Heisenburg's uncertainty principle

$$\Delta x \Delta p \geqslant \frac{h}{4\pi}$$

This expression can be derived by considering the possible paths an electron might take as it passes through the slit.

(i) Write an expression for Δx in terms of slit width *b*.

[1]

(ii) Write an expression for Δp in terms of diffraction angle θ.

[1]

(iii) Hence, show that

$$\Delta x \Delta p \approx \frac{p\lambda}{2}$$

[2]

(4 marks)

(b) Outline the effects on the range of diffraction angles and the uncertainties of position and momentum expected when

(i) The width of the slit is increased.

[3]

(ii) The width of the slit is reduced.

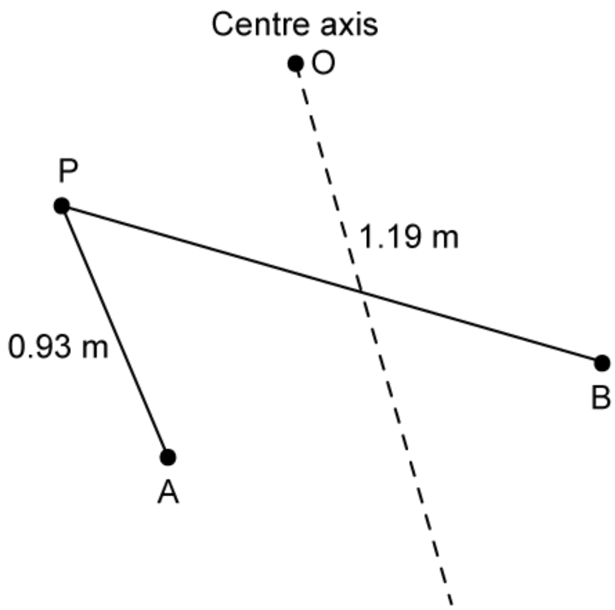
[3]

(6 marks)

5 (a) Two coherent sources, **A** and **B**, which are in phase with each other, emit microwaves of wavelength 40.0 mm. The amplitude of waves from source **B** is twice that of source **A**.

A detector is placed at the point **P** where it is 0.93 m from **A** and 1.19 m from **B**, as shown in **Figure 1**. The centre axis is normal and a bisector to the straight line joining **A** and **B**.

Figure 1



With reference to the phase of the microwaves, deduce the magnitude of the detected signal at **P** and explain your reasoning.

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(3 marks)

(b) Deduce, with suitable calculations, how the detected signal varies as the detector is moved from **P** to **O**.

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(5 marks)

(c) The source B is altered such that it emits waves that are 180° out of phase with source A.

Deduce the type of interference that now occurs at point P and explain your reasoning.

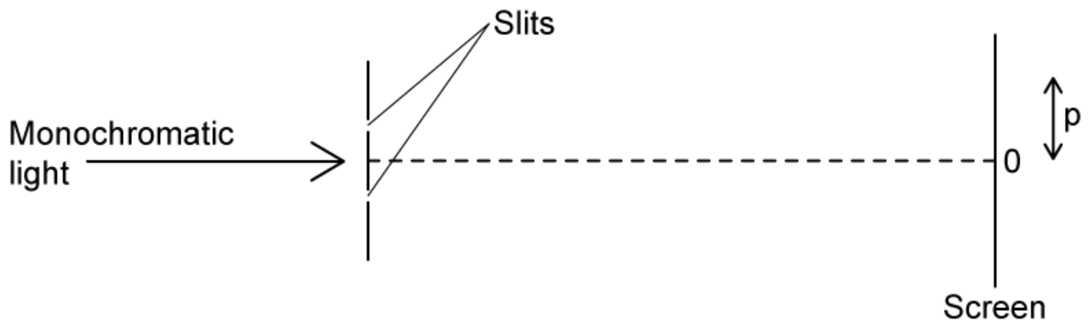
(2 marks)

6 Transverse, sinusoidal progressive waves of wavelength λ have points P and Q which are $\frac{5\lambda}{4}$ apart. The waves travel from P to Q.

With an appropriate sketch, discuss the motion of Q at the instant when P is displaced upwards but is moving downwards.

(3 marks)

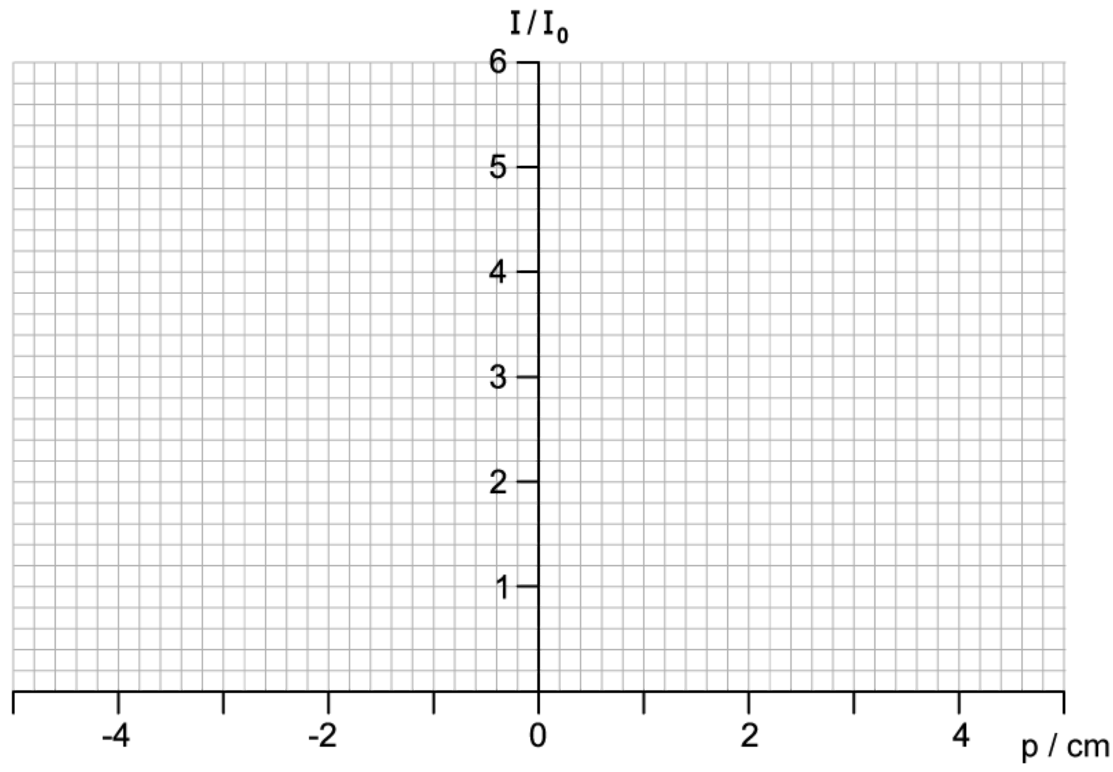
7 (a) Monochromatic light from a single source is incident on two thin parallel slits.



The following data are available:

- Distance from slits to screen = 4.5 m
- Wavelength = 690 nm
- Slit separation = 0.14 mm

The intensity, *I* of the light on the screen from each slit separately is I_0.



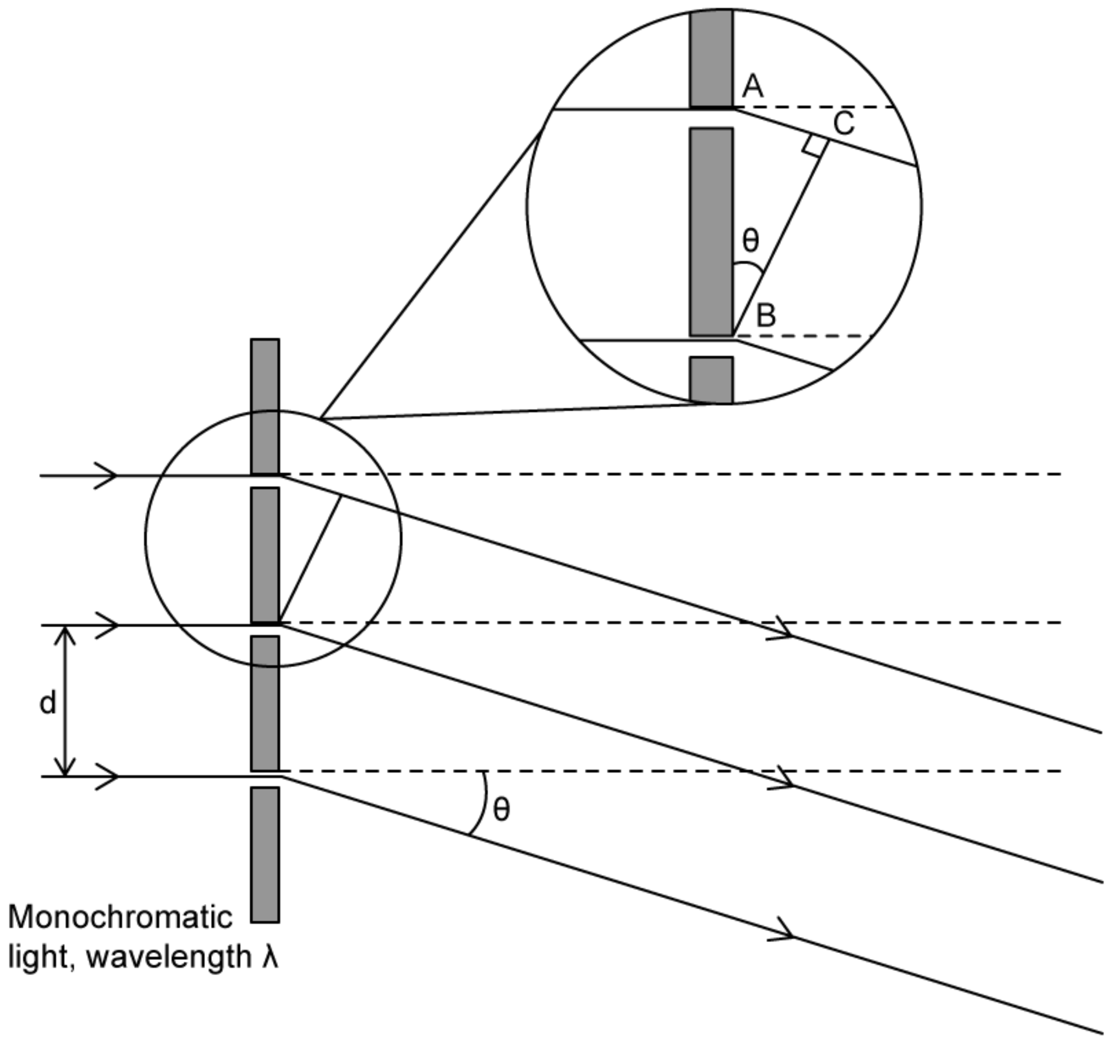
Sketch, on the axis, a graph to show variation with distance *p* on the screen against the intensity of light detected on the screen for this arrangement.

(3 marks)

(b) State and explain the changes that will occur to the diffraction pattern when the number of slits is increased from two to three.

(4 marks)

8 (a) Students in a laboratory have created the following set-up. Parallel rays of monochromatic light from two adjacent slits A and B of wavelength λ are incident normally on a diffraction grating with a slit separation *d.*



Use the diagram to derive the equation $n\lambda = d\sin\theta$ where θ is the angle of diffraction of a maxima order *n* visible on a screen.

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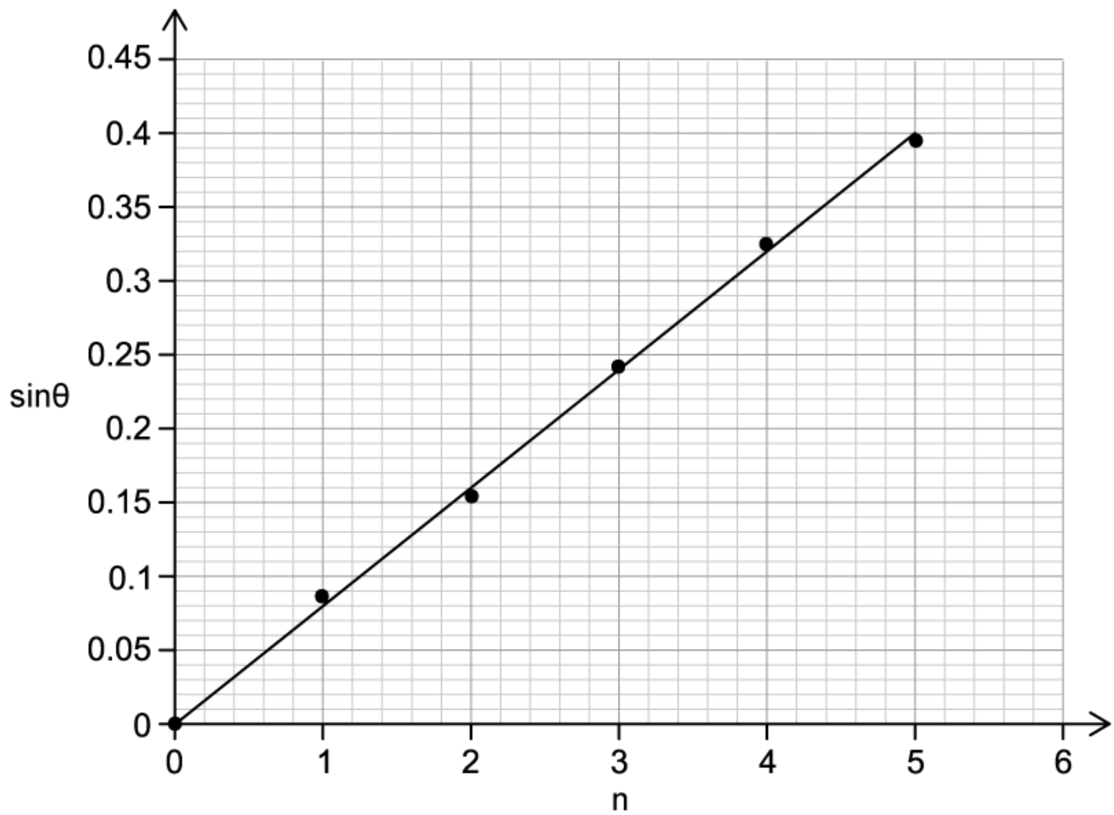
(6 marks)

(b) The monochromatic light in the set-up in part (a) has a wavelength of 545 nm. The graph shows the variation of sin*θ* with the order *n* of the maximum. The central order corresponds to *n* = 0.



Determine a mean value for the number of slits per mm of the grating.

(5 marks)

(c) The grating is 40 mm wide.

Determine the number of slits required to obtain a maximum of six bright fringes on the screen.

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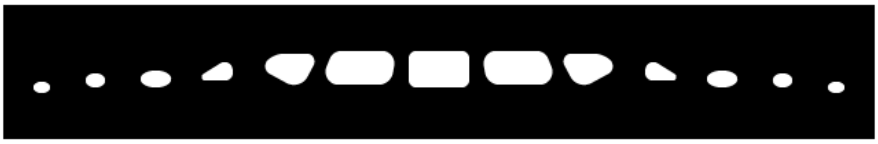
(3 marks)

(d) The students claim that they observed the following diffraction pattern on the screen for the grating from part (c).



State two reasons why the interference pattern obtained cannot be correct.

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(2 marks)

9 (a) A student designs an experiment to replicate Young's double slit demonstration.

The student opts to use a candle as a light source, with a piece of coloured filter paper to produce monochromatic light. They then consider additional apparatus required in order to observe an interference pattern.

Sketch a diagram, labelling all **apparatus** as well as any important **quantities**, to show the setup the student should use to produce and observe a diffraction pattern.

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(3 marks)

(b) The student labels the two slits on the double-slit grating slit X and slit Y. The student then paints over slit X, such that the intensity of light emerging from it is 50% of that emerging from slit Y.

Discuss the effects this change will have on the student's observations.

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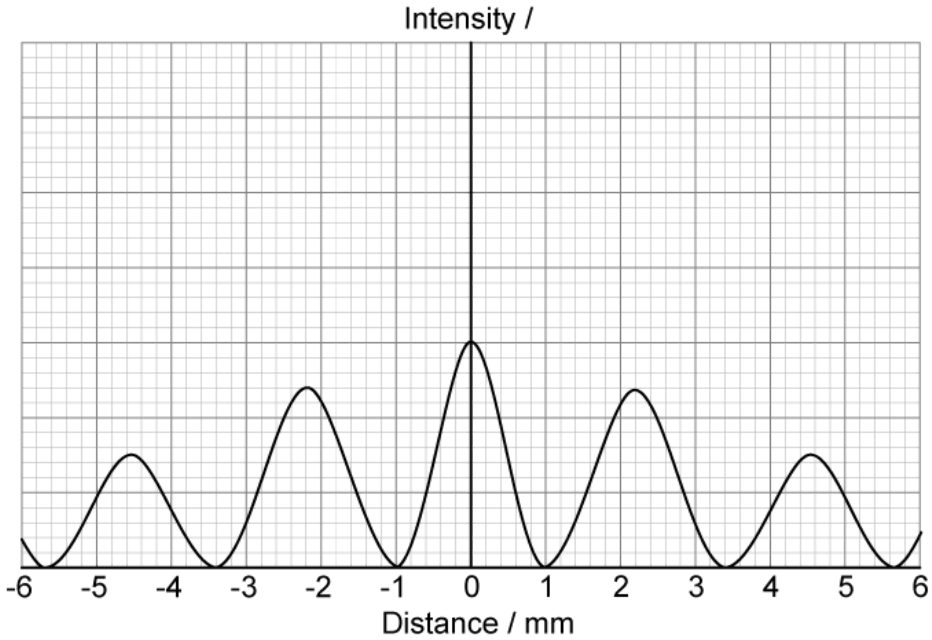
(4 marks)

(c) The student finishes setting up their apparatus and makes a quick note of two separate measurements, 0.75 mm and 2.0 m.

They then plot a graph of the intensity of light against the distance from the centre of the screen, represented by the origin.



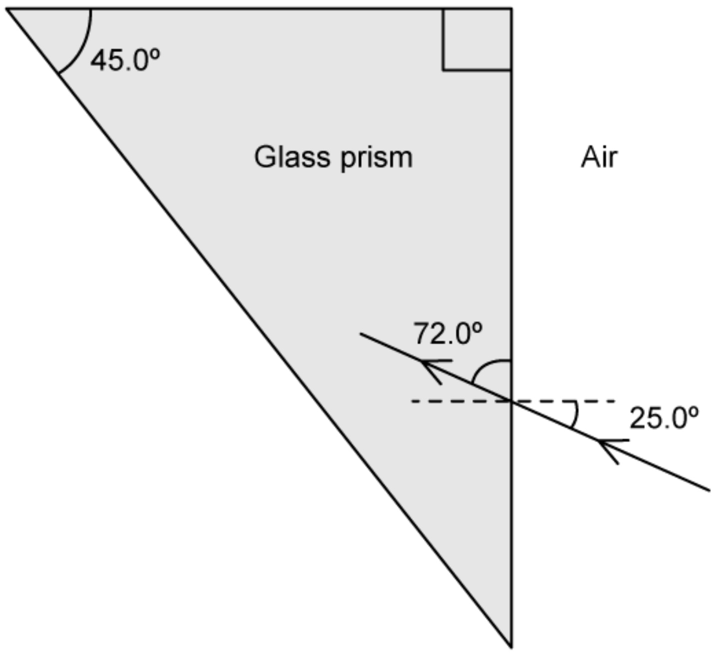
Determine which colour of filter paper the student most likely chose for this experiment.

(4 marks)

(d) Determine the phase angle between the waves meeting at the point that is 2.8 mm from the centre of the screen.

(2 marks)

10 (a) A ray of light passes from air into a glass prism.



As the light ray passes through the prism, it emerges back into the air.

Calculate the critical angle from the glass to the air.

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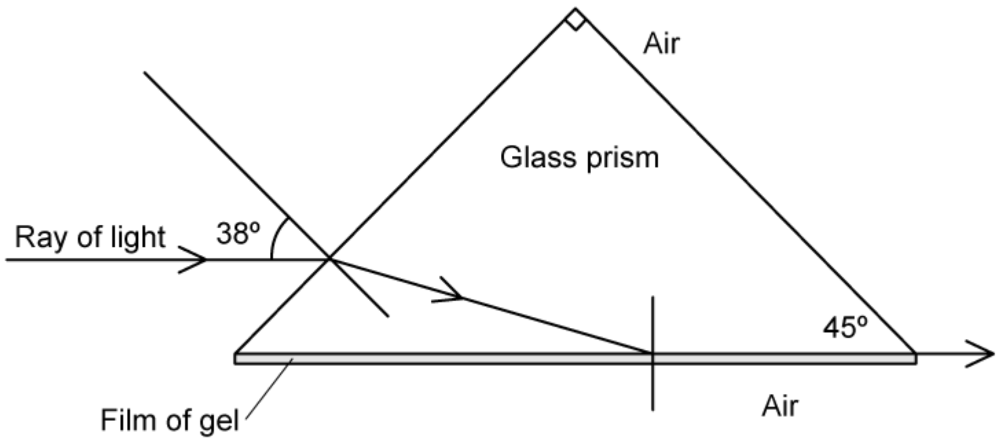
(2 marks)

(b) The prism is rotated and one side is coated with a film of transparent gel. A ray of light strikes the prism, at an angle of incidence of 38°, and continues through the glass to strike the glass–gel boundary at the critical angle.



Calculate the refractive index of the gel.

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(3 marks)

(c) A ray of light now strikes the prism at an angle of incidence which means that it now refracts straight through the gel at the glass–gel boundary.

Without calculation, explain how the critical angle for the glass–gel boundary differs from the critical angle for the gel–air boundary.

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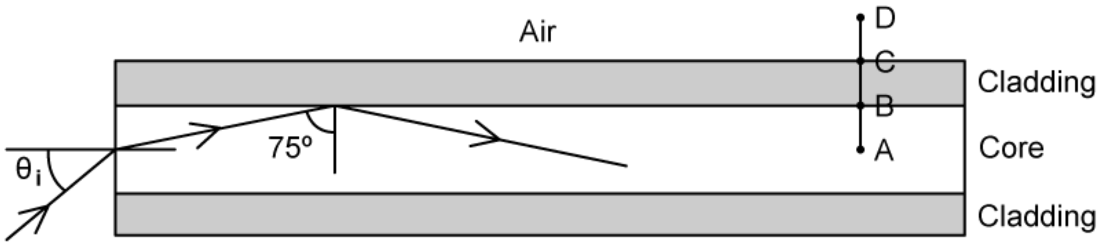
(2 marks)

11 (a) The diagram shows a cross–section through an optical fibre used in an endoscope. The critical angle is 7% lower than the 75° angle to the normal at the core–cladding boundary. The refractive index of the cladding is 1.4.



Calculate the angle of incidence θ_i at the air–core boundary.

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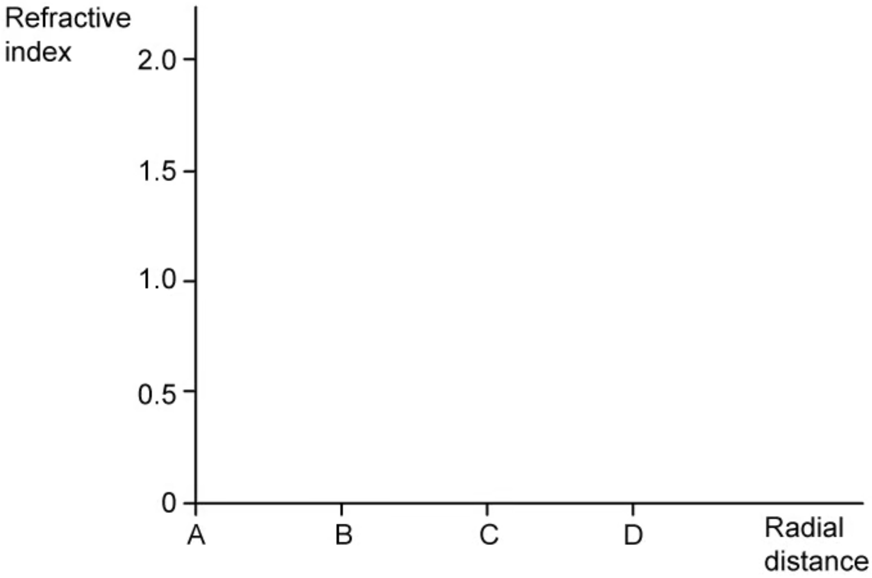
(4 marks)

(b) Complete the graph to show how the refractive index changes with radial distance along the line ABCD in Figure 2.



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(3 marks)