IB · DP · Physics

3 hours   14 questions

Structured Questions

9.2 Single-Slit Diffraction

9.2.1 The Nature of Single-Slit Diffraction / 9.2.2 Intensity of Interference Maxima & Minima

Easy (5 questions)	/59
Medium (5 questions)	/63
Hard (4 questions)	/41
Total Marks	**/163**

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Easy Questions

1 (a) State the features of a single-slit diffraction 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 ____________.

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(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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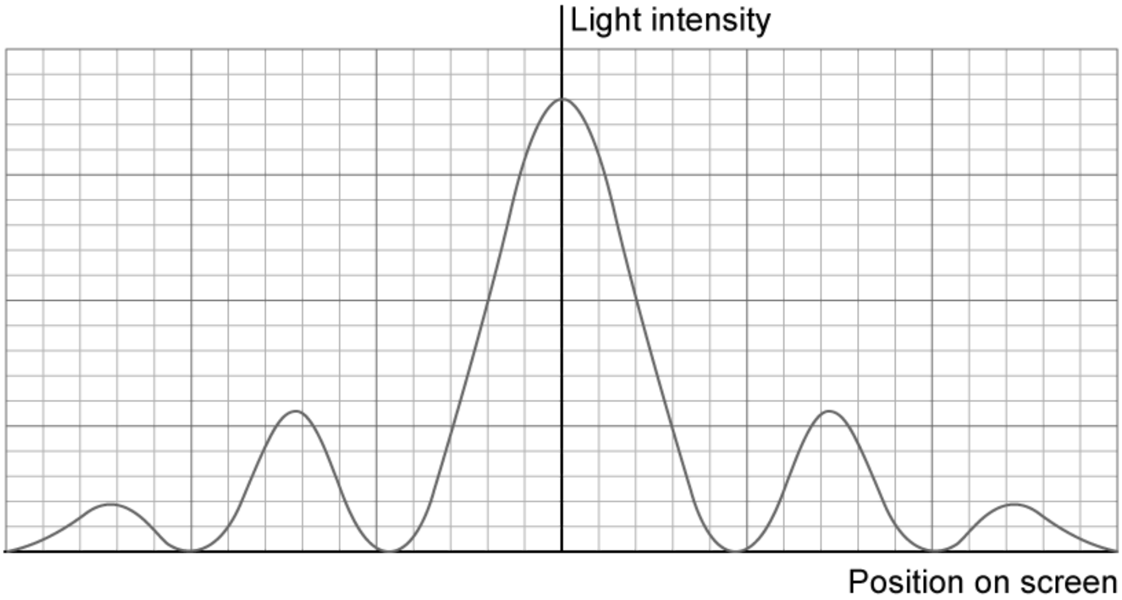
(2 marks)

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



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

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(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.

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(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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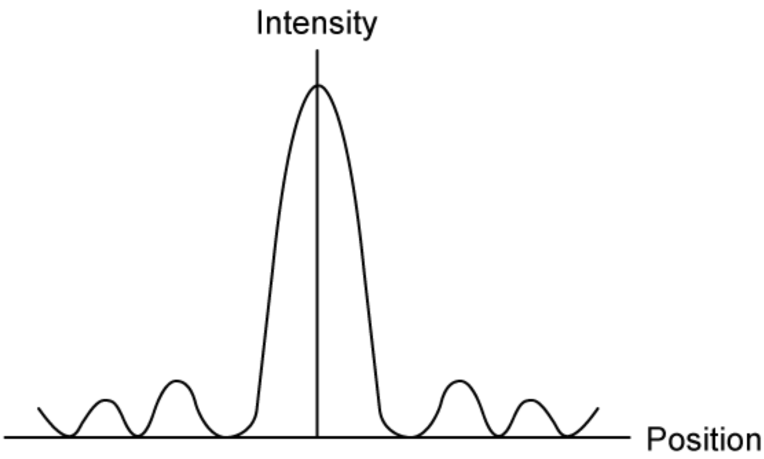
(2 marks)

(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]

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(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.

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(4 marks)

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

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(1 mark)

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

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(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)

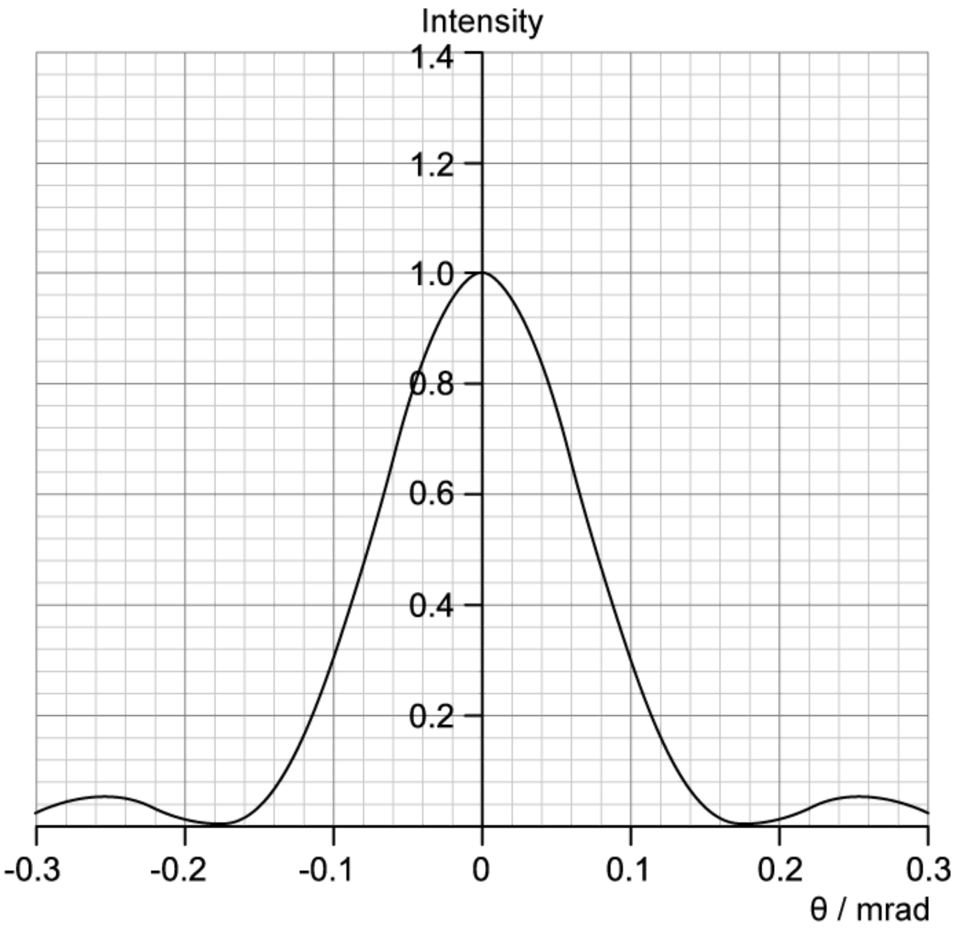
(d) Still using the same red laser, the students discussed the effect of decreasing the slit width by half.

(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)

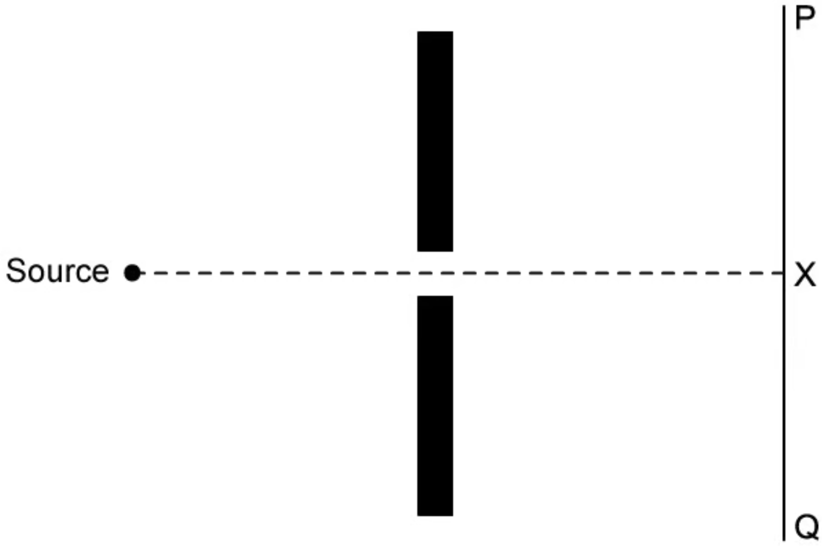
(d) Light with wavelength λ is incident upon a single slit of width b producing an angle of diffraction θ.

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)

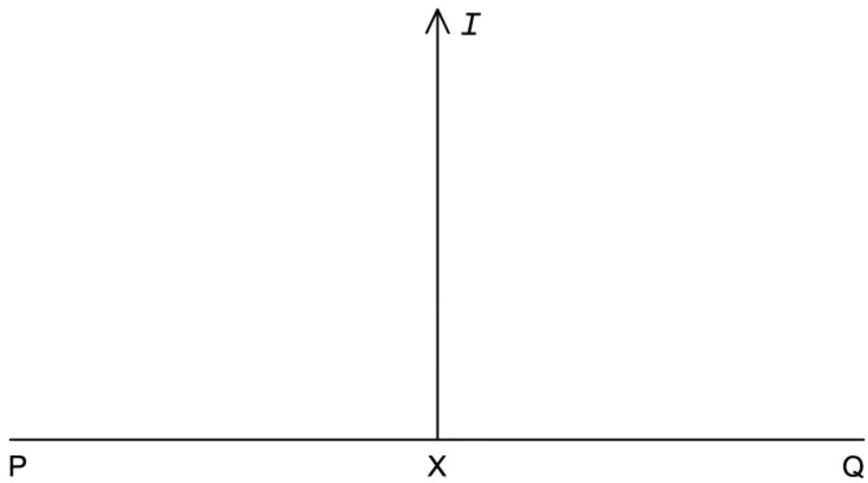
Medium Questions

1 (a) A source of sound is placed in front of a barrier that has an opening of width comparable to the wavelength of the sound.



A sound detector is moving along the line PQ. The centre PQ is marked X.

(i) On the axis below, sketch a graph to show how the intensity, *I* of the sound varies as the detector moves from P to Q.



[2]

(ii) State the effect on the intensity pattern of decreasing the wavelength of sound.

[1]

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(3 marks)

(b) The angle between the slit, X and the first location after X where sound is not detected is 102.8°. The slit has a width of 4 mm.

(i) Calculate the wavelength of the sound used in this experiment.

[1]

(ii) Calculate the path difference of the sound from both slits at this point.

[2]

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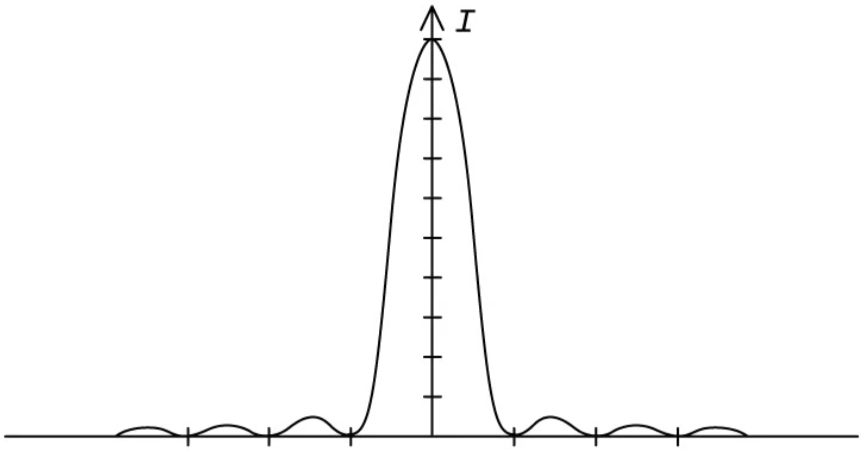
(3 marks)

(c) The width of the slit is now increased. Now, when the sound detector is moving along the line PQ, sound is detected at P, then at X and then at Q.

(i) Explain the effects of a wider slit on the diffraction pattern.

[2]

(ii) Label the points P, X and Q on the horizontal axis of the graph shown.



[2]

(4 marks)

(d) The slit width is now 30 m. The same source of sound is used throughout.

(i) Calculate the angle between the slit, X, and the first location where sound is detected after X.

[2]

(ii) Explain how moving the screen further away will change the interference pattern.

[2]

(4 marks)

2 (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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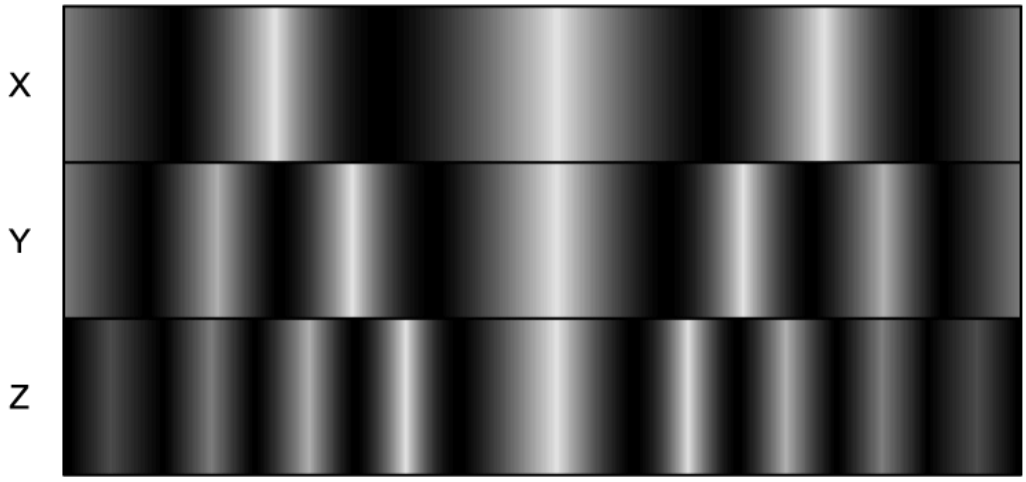
(3 marks)

(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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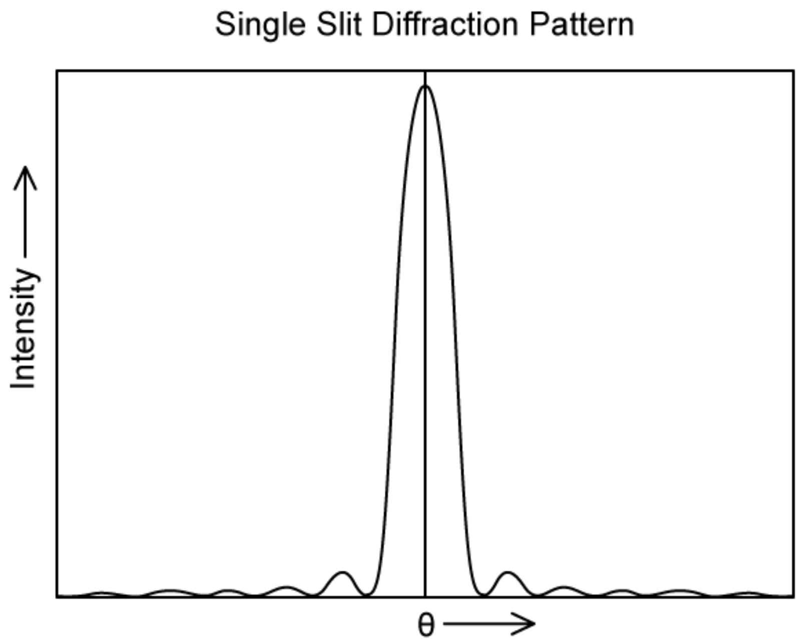
(4 marks)

(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.

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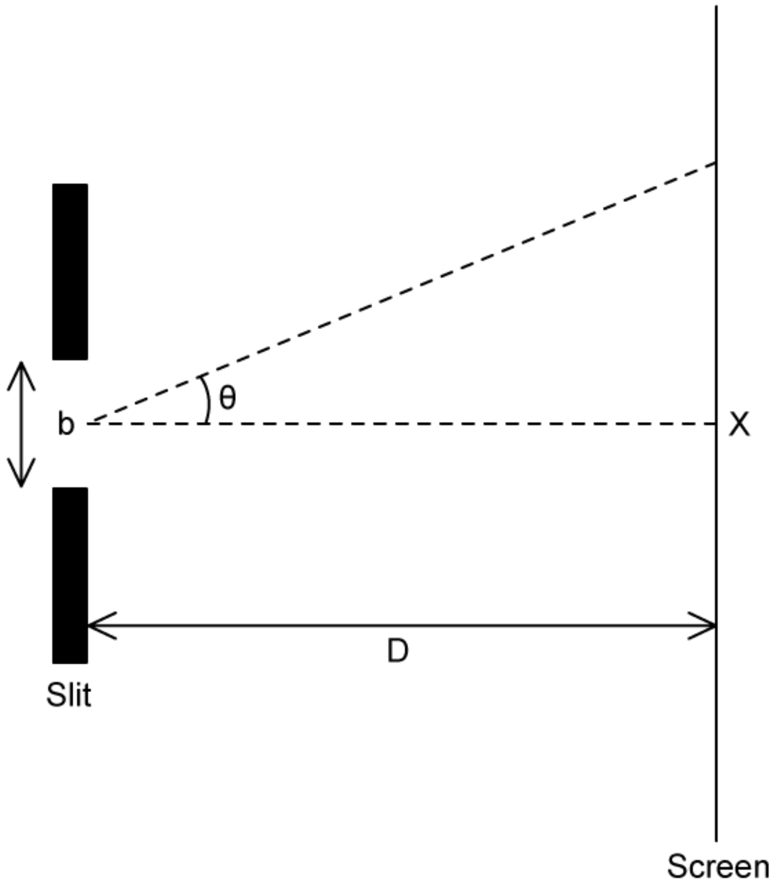
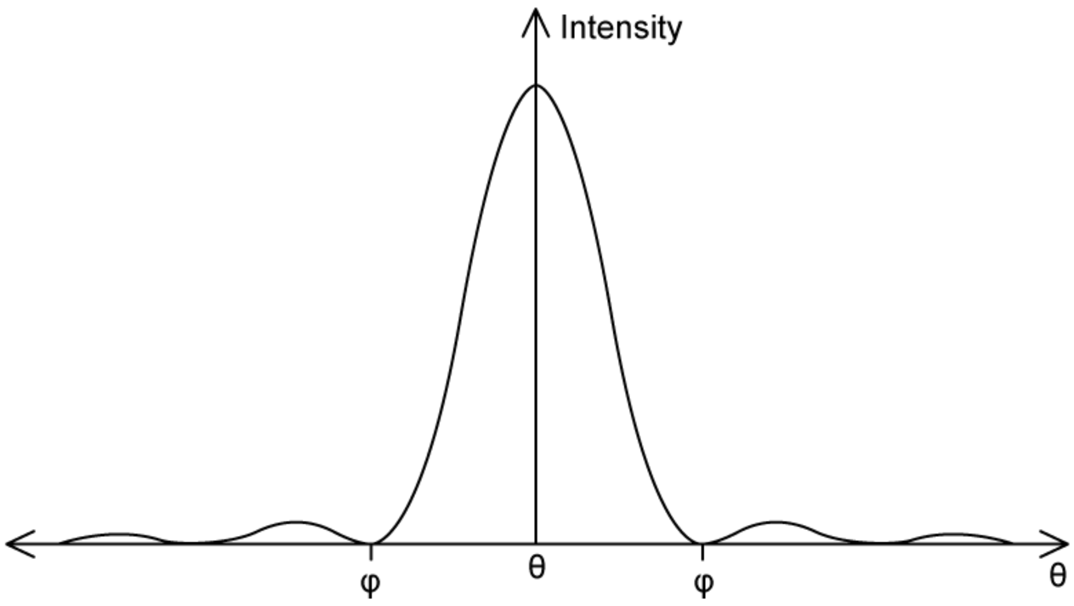
(2 marks)

3 (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 $\varphi = \dfrac{\lambda}{b}$ 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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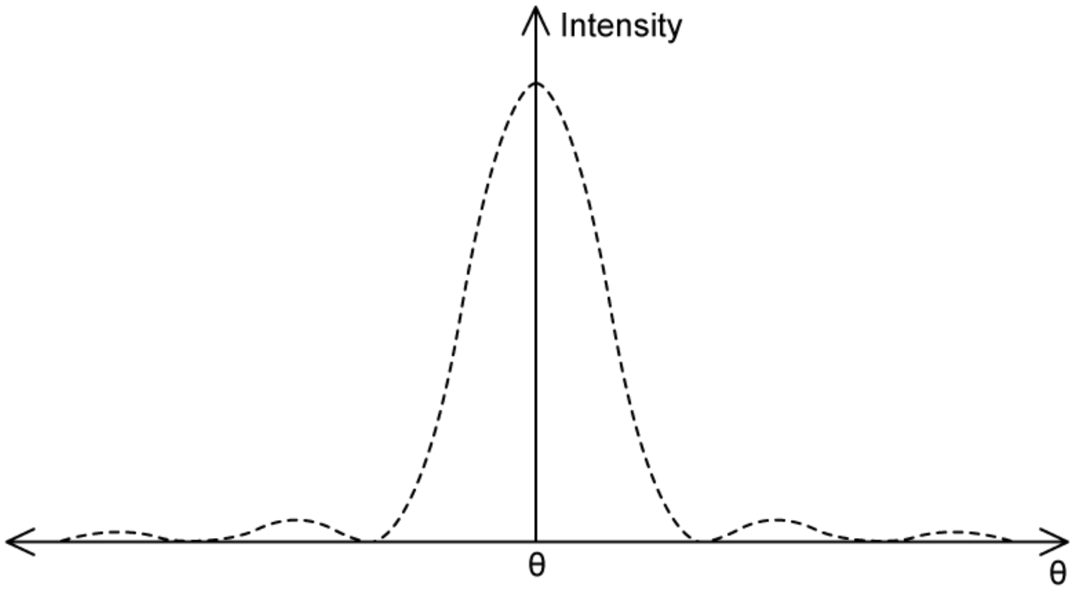
(2 marks)

(d) The single slit of width *b* is replaced with rectangular slits, of width 2. 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)

4 (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) Describe and explain what would happen to the diffraction angle if the slit width was made narrower.

[2]

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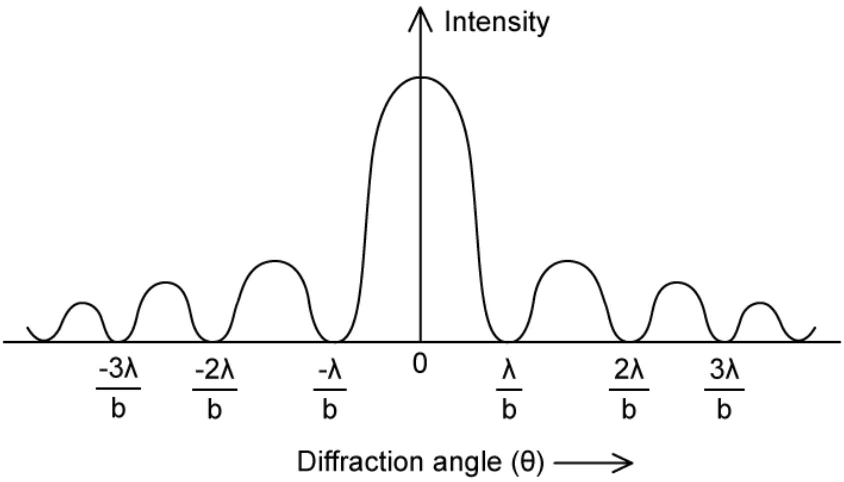
(3 marks)

(b) (i) Identify the first secondary maximum and the second diffraction minimum on the single slit intensity graph below.



[2]

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

[2]

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(4 marks)

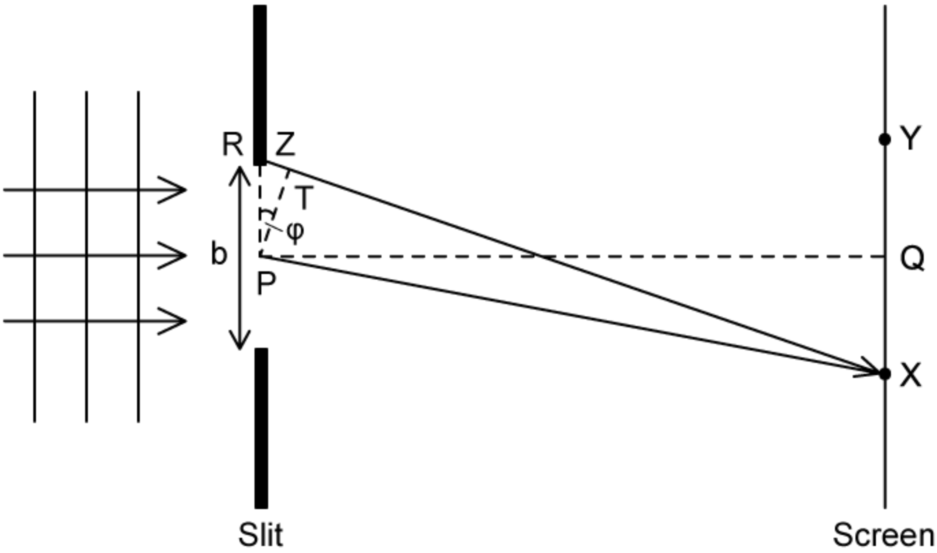
(c) Explain why the central maximum is white but the first secondary maximum at 12° is coloured.

(3 marks)

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

(3 marks)

5 (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)

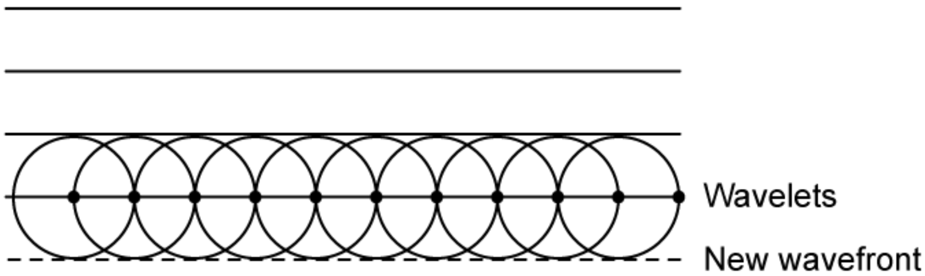
(d) In a certain demonstration of single-slit diffraction λ = 400 nm, b = 0.12 mm, and the screen is a long way from the slit.

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

(2 marks)

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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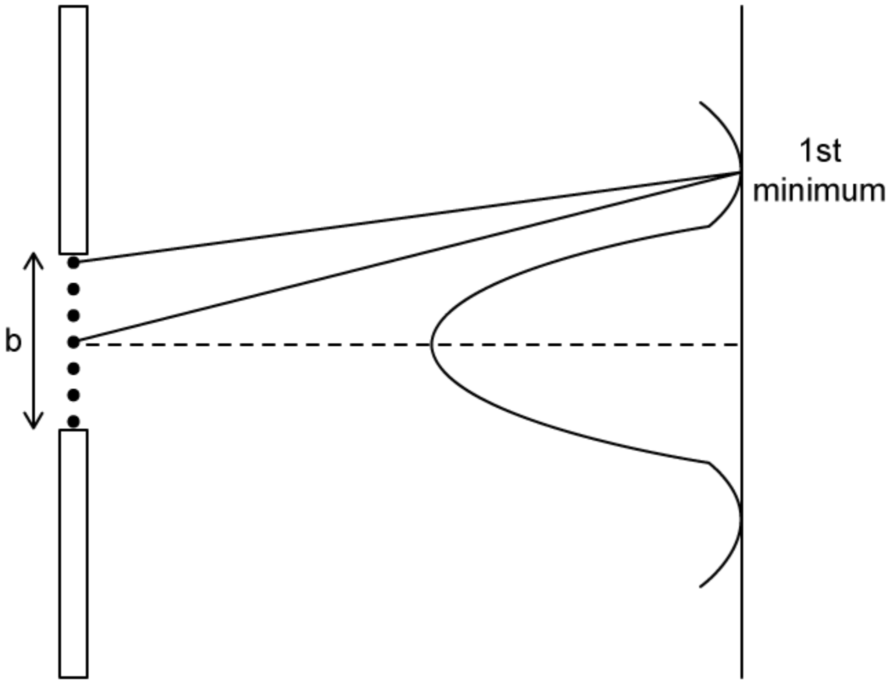
(4 marks)

(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.

(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:

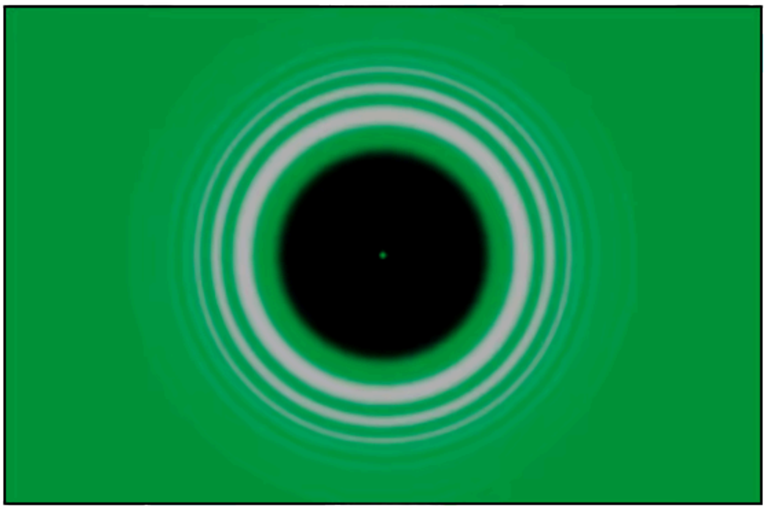
Green laser	Repeat 1	Repeat 2	Repeat 3	Repeat 4	Repeat 5
Distance from slit to screen, *D* / m	3.11	3.12	3.11	3.11	3.12
Slit width, *b* / mm	0.14	0.10	0.71	0.11	0.13
Width of central maximum, *w* / cm	2.8	2.7	2.9	2.9	2.6

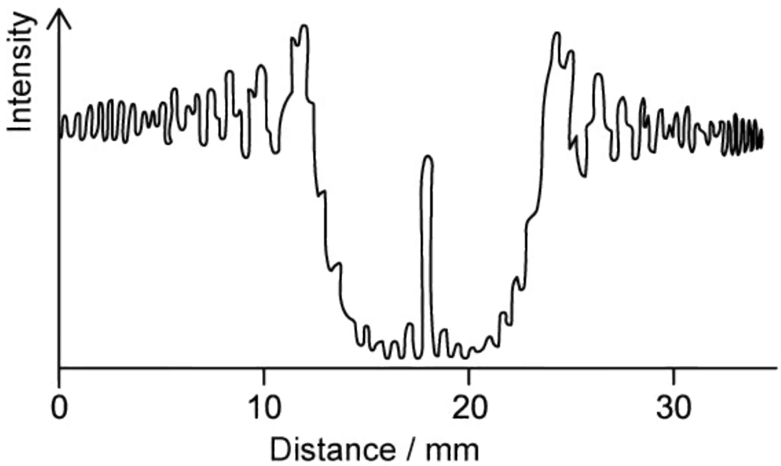
Calculate the wavelength of the laser and give its fractional uncertainty.

(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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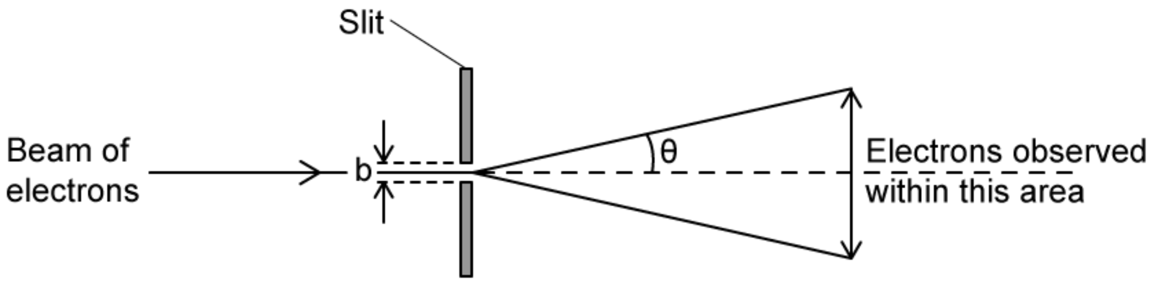
(2 marks)

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

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

(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]

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(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)