Diffraction Interference 2 *[49 marks]*

1. Monochromatic light of wavelength λ in air is incident normally on a thin film of refractive index *n*. The film is surrounded by air. The intensity of the reflected light is a minimum. What is a possible thickness of the film? *[1 mark]*

   A. $\frac{\lambda}{4n}$

   B. $\frac{3\lambda}{4n}$

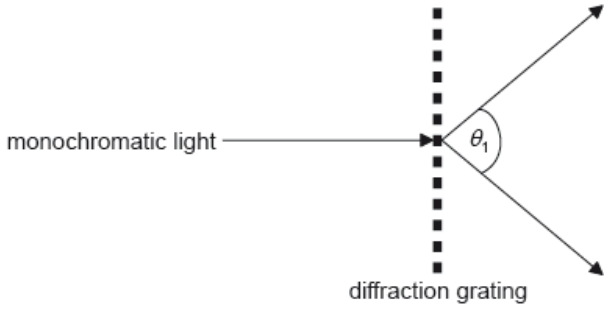
   C. $\frac{\lambda}{n}$

   D. $\frac{5\lambda}{4n}$

Markscheme

C

2. A beam of monochromatic light is incident on a diffraction grating of *N* lines per unit length. The angle between the first orders is θ_1. *[1 mark]*



What is the wavelength of the light?

A. $\frac{\sin\theta_1}{N}$

B. $N \sin \theta_1$

C. $N \sin\left(\frac{\theta_1}{2}\right)$

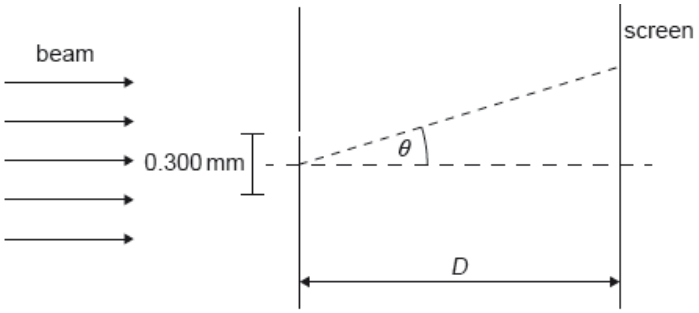
D. $\frac{\sin\left(\frac{\theta_1}{2}\right)}{N}$

Markscheme

D

A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

The beam is incident normally on a double slit. The distance between the slits is 0.300 mm. A screen is at a distance *D* from the slits. The diffraction angle θ is labelled.



3a. A series of dark and bright fringes appears on the screen. Explain how a dark fringe is formed. *[3 marks]*

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Markscheme

superposition of light from each slit / interference of light from both slits

with path/phase difference of any half-odd multiple of wavelength/any odd multiple of π (in words or symbols)

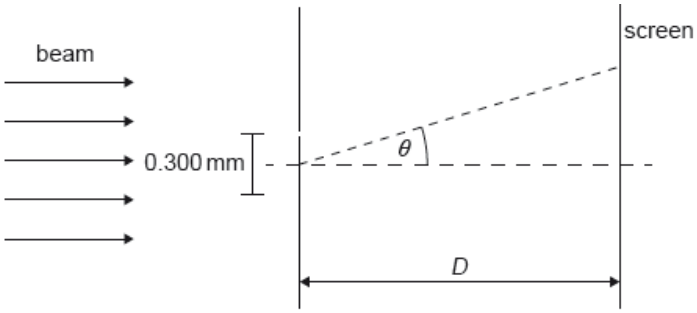
producing destructive interference

Ignore any reference to crests and troughs.

[3 marks]

A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

The beam is incident normally on a double slit. The distance between the slits is 0.300 mm. A screen is at a distance D from the slits. The diffraction angle θ is labelled.



3b. Outline why the beam has to be coherent in order for the fringes to be visible. *[1 mark]*

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Markscheme

light waves (from slits) must have constant phase difference / no phase difference / be in phase

OWTTE

[1 mark]

3c. The wavelength of the beam as observed on Earth is 633.0 nm. The separation between a dark and a bright fringe on the screen is 4.50 mm. Calculate *D*. *[2 marks]*

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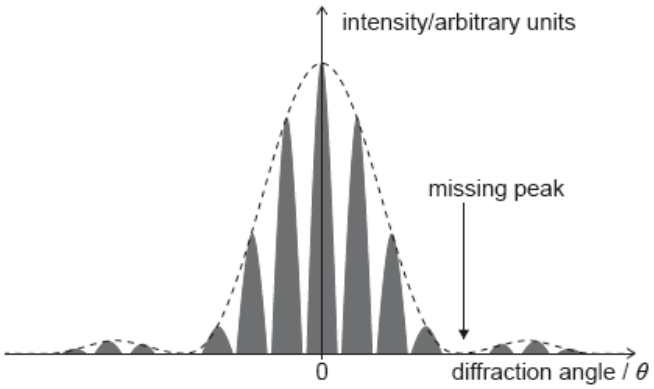
Markscheme

evidence of solving for D «$D = \frac{sd}{\lambda}$» ✔

«$\frac{4.50\times10^{-3}\times0.300\times10^{-3}}{633.0\times10^{-9}} \times 2$» = 4.27 «m» ✔

*Award **[1]** max for 2.13 m.*

The graph of variation of intensity with diffraction angle for this experiment is shown.



3d. Calculate the angular separation between the central peak and the missing peak in the double-slit interference intensity pattern. State your answer to an appropriate number of significant figures. *[3 marks]*

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Markscheme

$\sin\theta = \frac{4\times633.0\times10^{-9}}{0.300\times10^{-3}}$

$\sin\theta = 0.0084401...$

final answer to three sig figs (*eg* 0.00844 or 8.44×10^{-3})

Allow ECF from (a)(iii).

*Award **[1]** for 0.121 rad (can award MP3 in addition for proper sig fig)*

Accept calculation in degrees leading to 0.481 degrees.

Award MP3 for any answer expressed to 3sf.

[3 marks]

3e. Deduce, in mm, the width of one slit. *[2 marks]*

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Markscheme

use of diffraction formula «$b = \frac{\lambda}{\theta}$»

OR

$\frac{633.0 \times 10^{-9}}{0.00844}$

«=» 7.5«00» × 10^{-2} «mm»

Allow ECF from (b)(i).

[2 marks]

3f. The wavelength of the light in the beam when emitted by the galaxy was 621.4 nm. *[2 marks]*

Explain, without further calculation, what can be deduced about the relative motion of the galaxy and the Earth.

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Markscheme

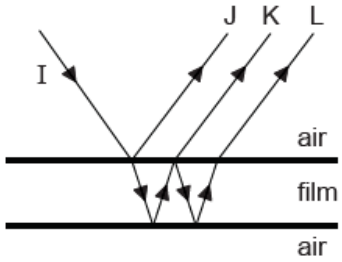
wavelength increases (so frequency decreases) / light is redshifted

galaxy is moving away from Earth

Allow ECF for MP2 (ie wavelength decreases so moving towards).

[2 marks]

4. A transparent liquid forms a parallel-sided thin film in air. The diagram shows a ray I incident on the upper air–film boundary at normal incidence (the rays are shown at an angle to the normal for clarity). *[1 mark]*



Reflections from the top and bottom surfaces of the film result in three rays J, K and L. Which of the rays has undergone a phase change of π rad?

A. J only

B. J and L only

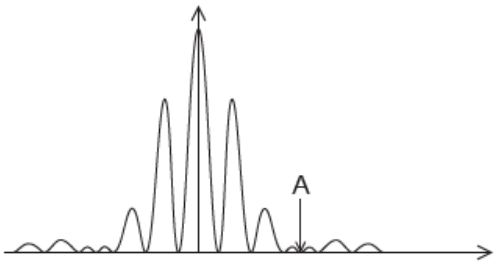
C. J and K only

D. J, K and L

Markscheme

A

Yellow light from a sodium lamp of wavelength 590 nm is incident at normal incidence on a double slit. The resulting interference pattern is observed on a screen. The intensity of the pattern on the screen is shown.



5a. Explain why zero intensity is observed at position A. *[2 marks]*

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Markscheme

the diagram shows the combined effect of «single slit» diffraction and «double slit» interference

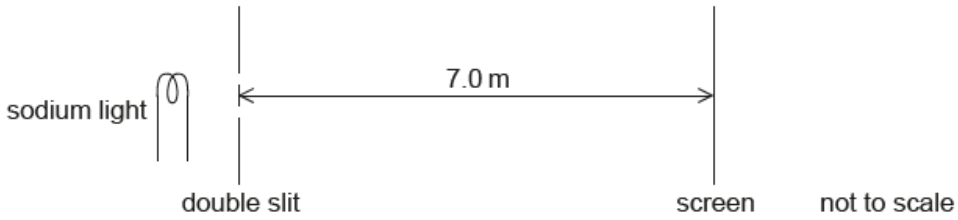
recognition that there is a minimum of the single slit pattern

OR

a missing maximum of the double slit pattern at A

waves «from the single slit» are in antiphase/cancel/have a path difference of $(n + \frac{1}{2})\lambda$/destructive interference at A

5b. The distance from the centre of the pattern to A is 4.1 x 10^{-2} m. The distance from the screen to the slits is 7.0 m. *[2 marks]*



Calculate the width of each slit.

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Markscheme

$\theta = \frac{4.1\times10^{-2}}{7.0}$ ***OR*** $b = \frac{\lambda}{\theta}$ «= $\frac{7.0\times5.9\times10^{-7}}{4.1\times10^{-2}}$»

1.0×10^{-4} «m»

*Award **[0]** for use of double slit formula (which gives the correct answer so do not award BCA)*

Allow use of sin or tan for small angles

5c. Calculate the separation of the two slits. *[2 marks]*

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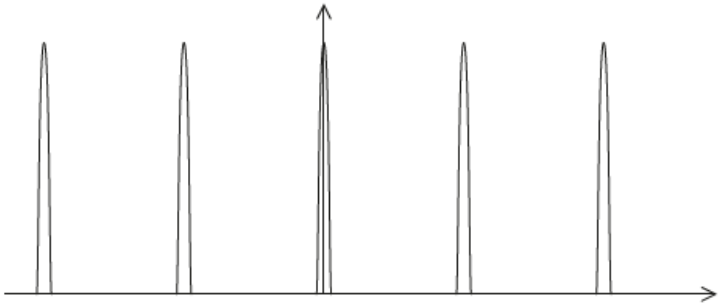
Markscheme

use of $s = \frac{\lambda D}{d}$ with 3 fringes «$\frac{590\times10^{-9}\times7.0}{4.1\times10^{-2}}$»

3.0×10^{-4} «m»

Allow ECF.

The double slit is replaced by a diffraction grating that has 600 lines per millimetre. The resulting pattern on the screen is shown.



5d. State and explain the differences between the pattern on the screen due to the grating and the pattern due to the double slit. *[3 marks]*

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Markscheme

fringes are further apart because the separation of slits is «much» less

intensity does not change «significantly» across the pattern ***or*** diffraction envelope is broader because slits are «much» narrower

the fringes are narrower/sharper because the region/area of constructive interference is smaller/there are more slits

intensity of peaks has increased because more light can pass through

*Award **[1 max]** for stating one or more differences with no explanation*

*Award **[2 max]** for stating one difference with its explanation*

*Award **[MP3]** for a second difference with its explanation*

Allow "peaks" for "fringes"

5e. The yellow light is made from two very similar wavelengths that produce two lines in the spectrum of sodium. The wavelengths are 588.995 nm and 589.592 nm. These two lines can just be resolved in the second-order spectrum of this diffraction grating. Determine the beam width of the light incident on the diffraction grating. *[3 marks]*

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Markscheme

$\Delta\lambda = 589.592 - 588.995$

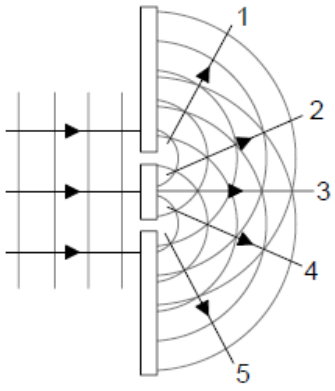
OR

$\Delta\lambda = 0.597$ «nm»

$N = «\frac{\lambda}{m\Delta\lambda}$ =» $\frac{589}{2\times 0.597}$ «493»

beam width = «$\frac{493}{600}$ =» 8.2 x 10^{-4} «m» ***or*** 0.82 «mm»

6. Blue light is incident on two narrow slits. Constructive interference takes place along the lines labelled 1 to 5. *[1 mark]*



The blue light is now replaced by red light. What additional change is needed so that the lines of constructive interference remain in the same angular positions?

A. Make the slits wider

B. Make the slits narrower

C. Move the slits closer together

D. Move the slits further apart

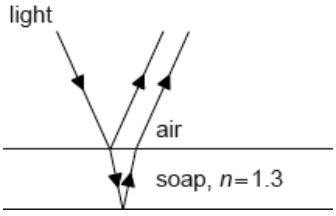
Markscheme

D

This question is about thin-film interference.

Monochromatic light with wavelength 572 nm is incident from air on a thin soap film.

The soap solution has a refractive index of 1.3.



7a. Calculate the wavelength of the light within the soap solution. *[1 mark]*

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Markscheme

$\lambda' = \frac{\lambda}{1.33} = \frac{572}{1.3} = 440 \text{ nm};$

7b. Calculate the minimum thickness of the soap film that results in constructive interference for the reflected light. *[1 mark]*

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Markscheme

110 nm;

7c. Without a calculation, explain why a soap film that is twice as thick as that calculated in (b) results in destructive interference. *[2 marks]*

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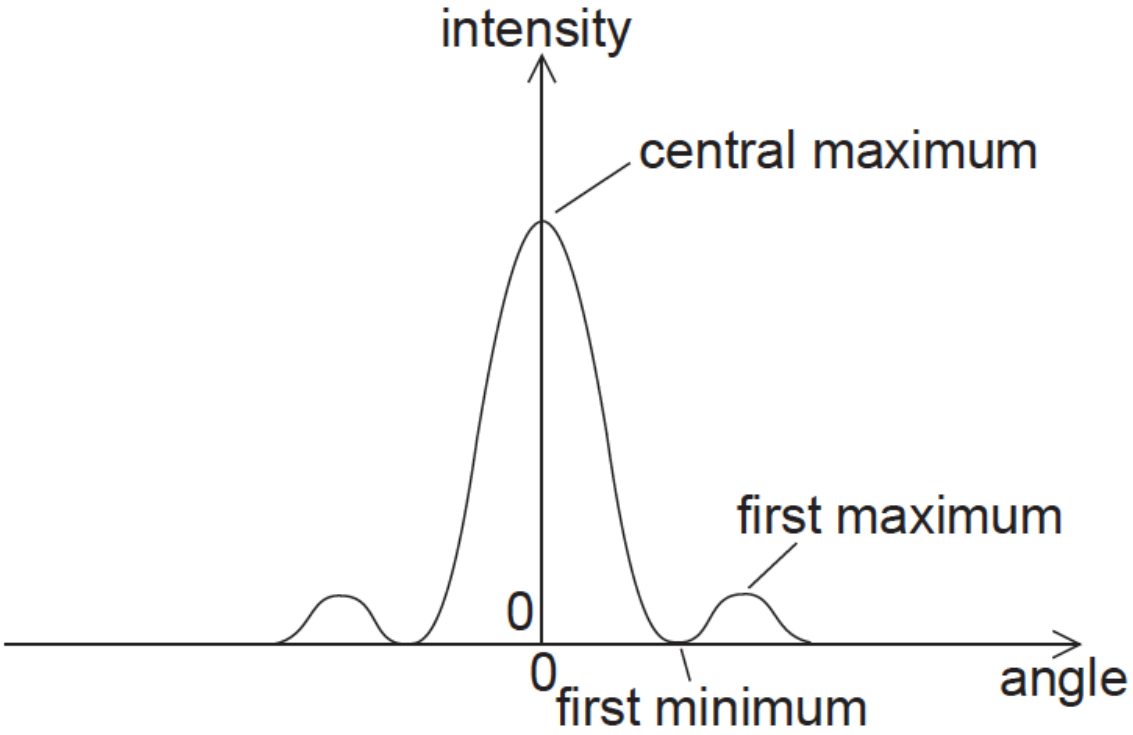
Markscheme

there would be a full wavelength within the film;

but the phase change at the first surface means that there is always destructive interference;

8. The graph below shows the variation of the intensity of light with angle for the diffraction pattern produced when light is diffracted by a slit. *[1 mark]*



According to the Rayleigh criterion, when the diffraction patterns of two slits are just resolved

A. the first maximum of one diffraction pattern coincides with the central maximum of the other diffraction pattern.

B. the central maximum of one diffraction pattern coincides with the central maximum of the other diffraction pattern.

C. the first minimum of one diffraction pattern coincides with the central maximum of the other diffraction pattern.

D. the first minimum of one diffraction pattern coincides with the first minimum of the other diffraction pattern.

Markscheme

C

9. Green light is emitted by two point sources. The light passes through a narrow slit and is received by an observer. The images of the two sources just fail to be resolved. Which change allows for the images to be resolved? *[1 mark]*

A. Replacing the narrow slit with a circular aperture of same size.

B. Moving the two sources further from the aperture.

C. Using red light.

D. Using violet light.

Markscheme

D

This question is about resolution and polarization.

10a. State the Rayleigh criterion. *[2 marks]*

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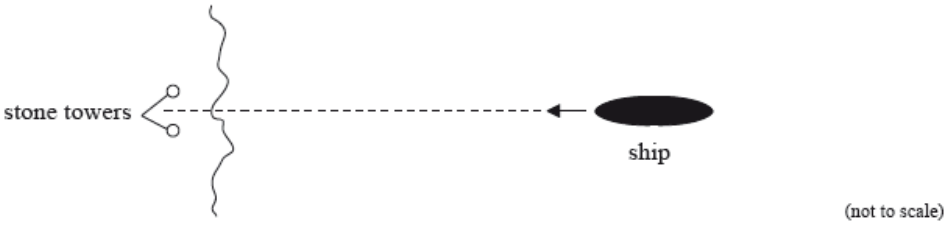
Markscheme

for the images (of two sources) just to be resolved/distinguished/seen as separate;

central maximum of one diffraction pattern must coincide with first minimum of second / *OWTTE*;

Accept a suitably drawn diagram for the second marking point.

A ship sails towards two stone towers built on land.



(not to scale)

Emlyn, who is on the ship, views the towers. The pupils of Emlyn's eyes are each of diameter 2.0 mm. The average wavelength of the sunlight is 550 nm.

10b. (i) Calculate the angular separation of the two towers when the images of the towers are just resolved by Emlyn. *[3 marks]*

(ii) Emlyn can just resolve the images of the two towers when his distance from the towers is 11 km. Determine the distance between the two towers.

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Markscheme

(i) $\theta = \left(\frac{1.22\times550\times10^{-9}}{2.0\times10^{-3}} =\right) \ 3.4\times10^{-4}\ (\text{rad})$ ***or*** 0.019°;

(ii) $d = 11\times10^{3}\times3.4\times10^{-4}$;

$= 3.7\ (\text{m})$;

*Award **[2]** for a bald correct answer.*

10c. Emlyn puts on a pair of polarizing sunglasses. Explain how these sunglasses reduce the intensity of the light, reflected from the sea, that enters Emlyn's eyes. *[2 marks]*

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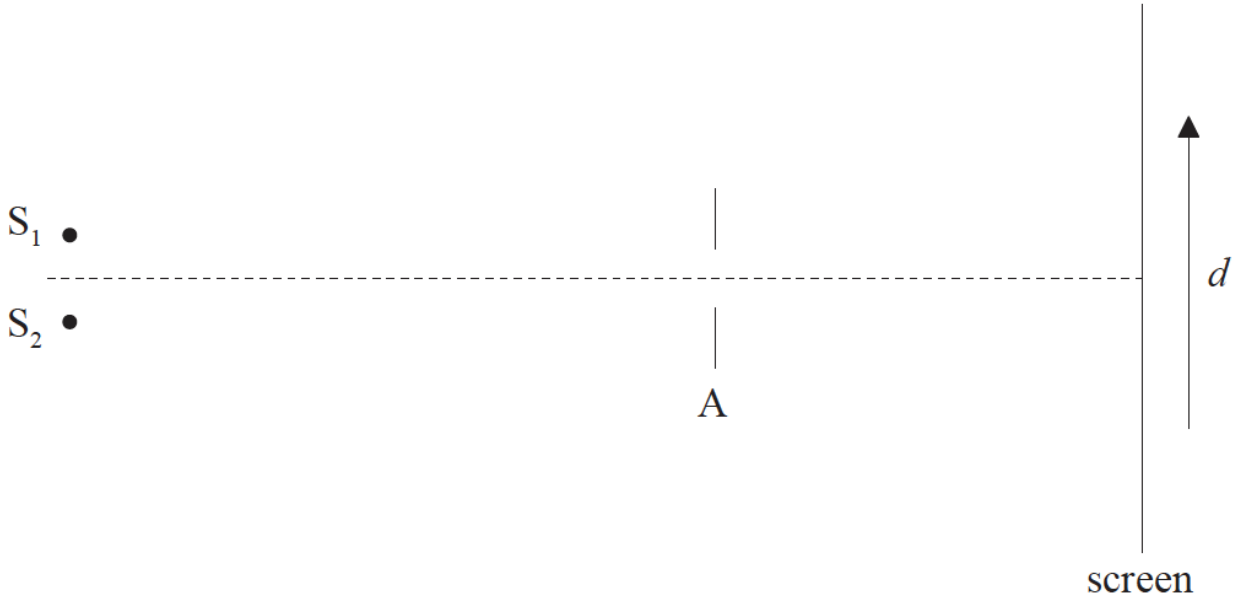
Markscheme

reflected light is (partially) polarized parallel to sea surface/horizontally polarized;

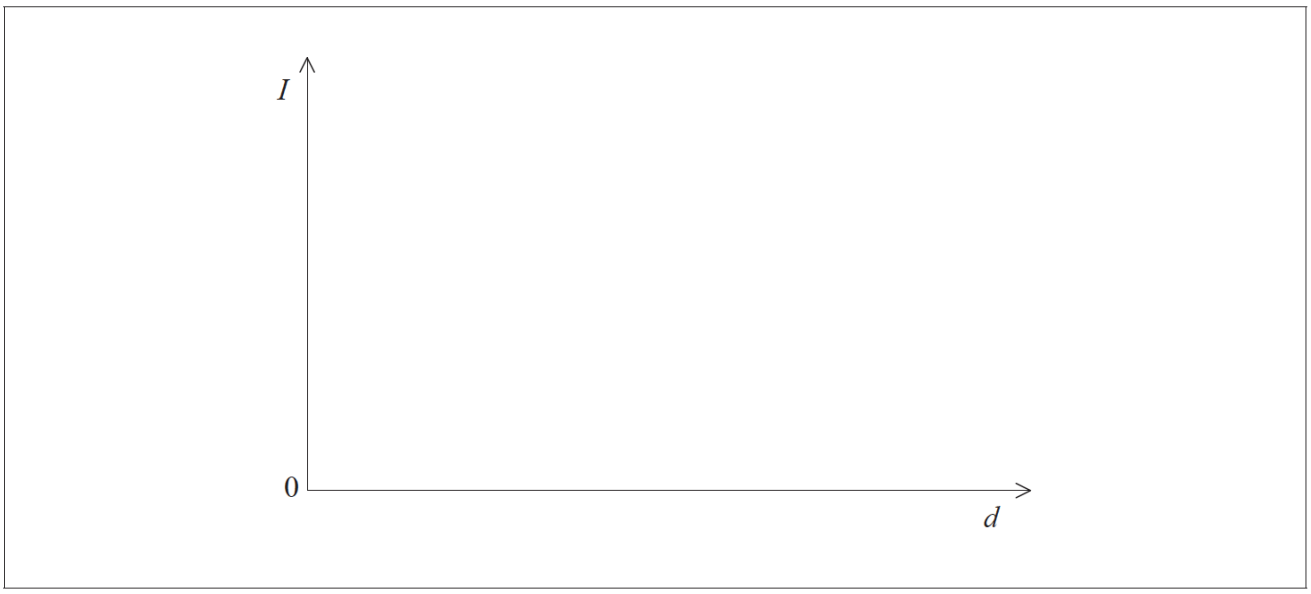
sunglasses have a transmission axis at 90° to reflected light/vertical transmission axis;

This question is about resolution.

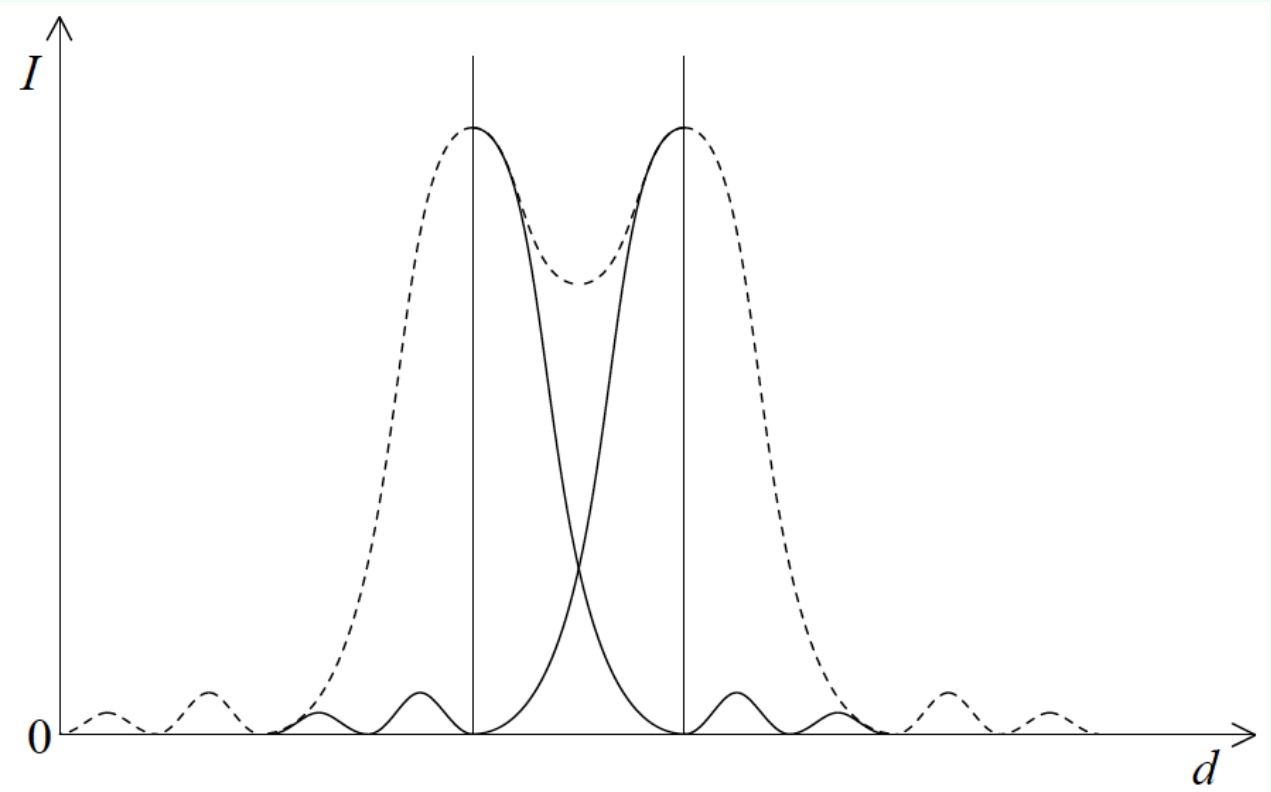
11a. Two point sources S_1 and S_2 emit monochromatic light of the same wavelength. The light is incident on a small aperture A and is then brought to focus on a screen. *[3 marks]*



The images of the two sources on the screen are just resolved according to the Rayleigh criterion. Sketch, using the axes below, how the relative intensity *I* of light on the screen varies with distance along the screen *d*.



Markscheme



correct shape of two diffraction patterns showing central maximum and at least one secondary maximum each side of central maximum;
intensity of secondary maxima no greater than one third intensity of central maxima; } *(judge by eye)*
first minimum of one pattern coincident with central maximum of other pattern;

or

Allow just the approximate dotted resultant intensity patterns:
correct pattern of two symmetrical principal maxima;
with local minimum between them;
at least one secondary maximum on each side which are no more than $\frac{1}{3}$ of the intensity of the principal maxima;

11b. A car is travelling at night along a straight road. Diane is walking towards the car. She sees the headlights of the car as one single light. *[3 marks]*

Estimate, using the data below, the separation *d* between Diane and the car at which, according to the Rayleigh criterion, Diane will just be able to see the headlights as two separate sources.

Distance between the headlights = 1.4 m
Average wavelength of light emitted by the headlights = 500 nm
Diameter of the pupils of Diane's eyes = 1.9 mm

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Markscheme

angular separation for resolution=
$1.22\frac{\lambda}{b} = 1.22 \times \frac{5.0\times10^{-7}}{1.9\times10^{-3}} = \left(3.21 \times 10^{-4}\right)(\text{rad})$;
$=\frac{1.4}{d}$;
d=4.4(km);
*Award **[2 max]** if 1.22 not used and answer is 5.3 km.*
*Award **[3]** for a bald correct answer.*

11c. The light from the car headlights in (b) is not polarized. State what is meant by polarized light. *[1 mark]*

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Markscheme

light in which the electric/magnetic field (vector) vibrates only in one plane/direction;