Interference and Resolution *[84 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. $\frac{5\lambda}{4n}$

2. Monochromatic light is incident on 4 rectangular, parallel slits. The first principal maximum is observed at an angle θ to the direction of the incident light. The number of slits is increased to 8 each having the same width and spacing as the first 4. *[1 mark]*

   Three statements about the first principal maximum with 8 slits are

   I. the angle at which it is observed is greater than θ

   II. its intensity increases

   III. its width decreases.

   Which statements are correct?

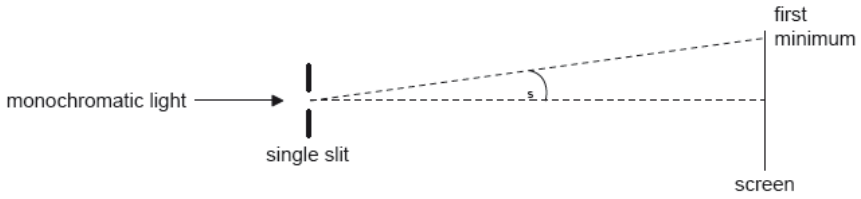
   A. I and II only

   B. I and III only

   C. II and III only

   D. I, II and III

3. A beam of monochromatic light is incident on a single slit and a diffraction pattern forms on the screen. *[1 mark]*



   What change will increase θ_s?

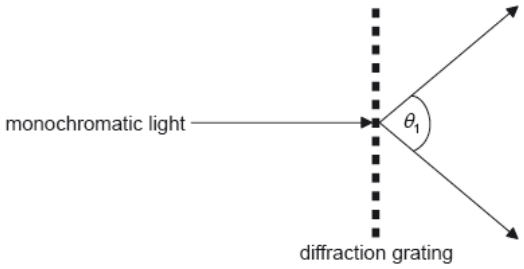
   A. Increase the width of the slit

   B. Decrease the width of the slit

   C. Increase the distance between the slit and the screen

   D. Decrease the distance between the slit and the screen

4. 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. $N \sin \theta_1$

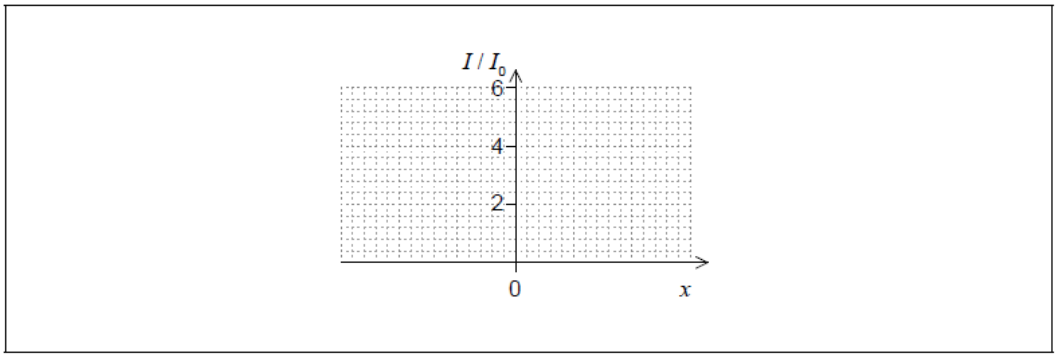
C. $N \sin \left(\frac{\theta_1}{2}\right)$

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

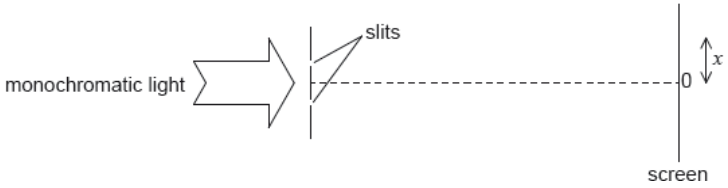
5a. Monochromatic light from two identical lamps arrives on a screen. *[1 mark]*

The intensity of light on the screen from each lamp separately is I_0.

On the axes, sketch a graph to show the variation with distance x on the screen of the intensity I of light on the screen.



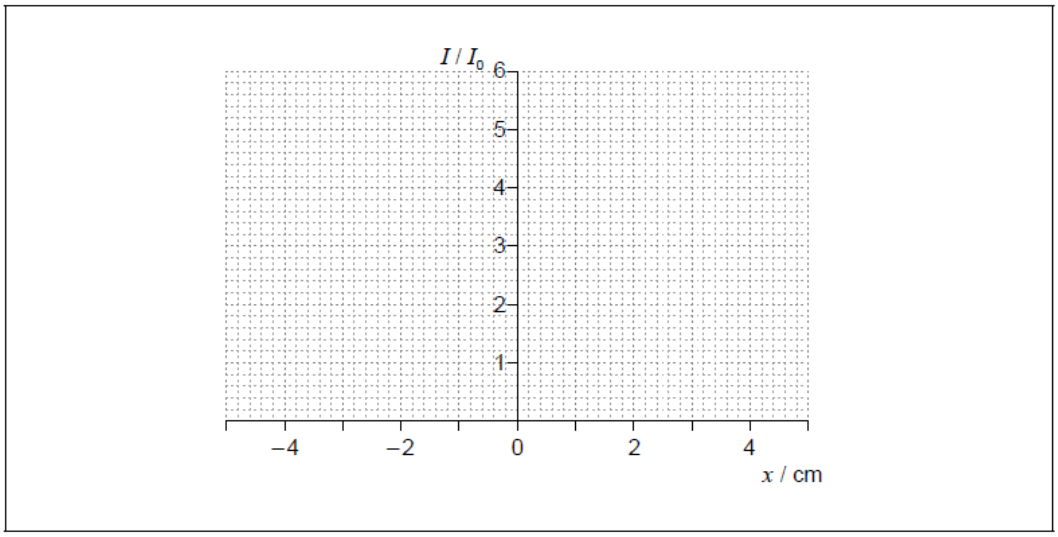
5b. Monochromatic light from a single source is incident on two thin, parallel slits. *[3 marks]*



The following data are available.

Slit separation	$= 0.12$ mm
Wavelength	$= 680$ nm
Distance to screen	$= 3.5$ m

The intensity I of light at the screen from each slit separately is I_0. Sketch, on the axes, a graph to show the variation with distance x on the screen of the intensity of light on the screen for this arrangement.



5c. The slit separation is increased. Outline **one** change observed on the screen. *[1 mark]*

6. Monochromatic light is incident on two identical slits to produce an interference pattern on a screen. One slit is then covered so that no light emerges from it. What is the change to the pattern observed on the screen? *[1 mark]*

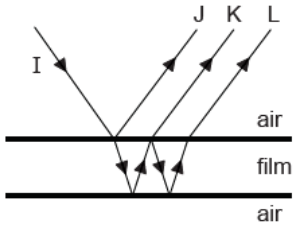
A. Fewer maxima will be observed.

B. The intensity of the central maximum will increase.

C. The outer maxima will become narrower.

D. The width of the central maximum will decrease.

7. 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

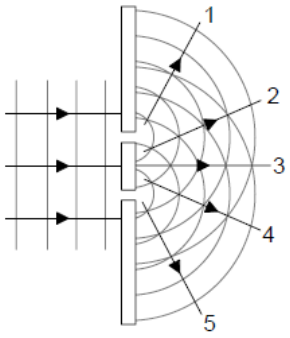
D. J, K and L

8. For fringes to be observed in a double-slit interference experiment, the slits must emit waves that are coherent. *[1 mark]*

What conditions are required for the frequency of the waves and for the phase difference between the waves so that the waves are coherent?

	Frequency of waves	Phase difference between waves
A.	same	variable
B.	same	constant
C.	constant difference	variable
D.	constant difference	constant

9. 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?

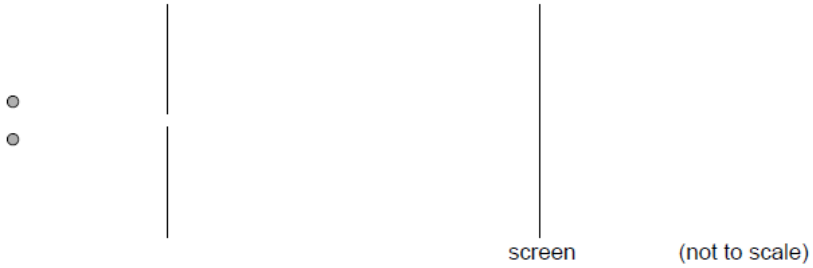
A. Make the slits wider

B. Make the slits narrower

C. Move the slits closer together

D. Move the slits further apart

10. Two points illuminated by monochromatic light are separated by a small distance. The light from the two sources passes through a small circular aperture and is detected on a screen far away. *[1 mark]*

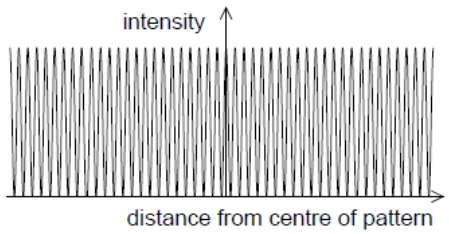


Two points illuminated by monochromatic light are separated by a small distance. The light from the two sources passes through a small circular aperture and is detected on a screen far away.

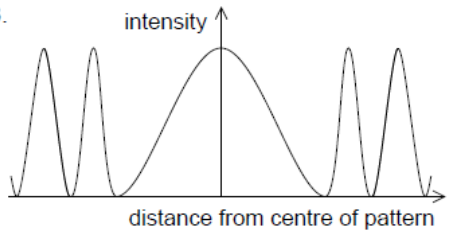
	Wavelength	Size of aperture
A.	increase	increase
B.	increase	decrease
C.	decrease	increase
D.	decrease	decrease

11. Monochromatic light is incident on a double slit. Both slits have a finite width. The light then forms an interference pattern on a screen some distance away. Which graph shows the variation of intensity with distance from the centre of the pattern? *[1 mark]*

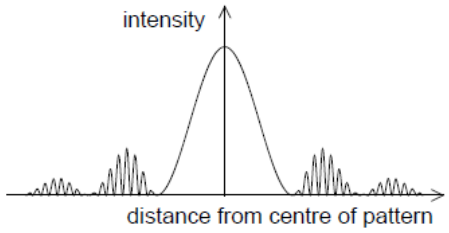
A.



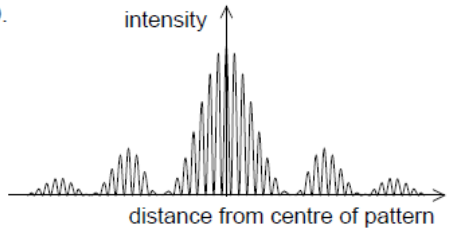
B.



C.



D.



12. Light of wavelength λ is incident normally on a diffraction grating that has a slit separation of $\frac{7\lambda}{2}$. What is the greatest number of maxima that can be observed using this arrangement? *[1 mark]*

A. 4
B. 6
C. 7
D. 9

13. A diffraction grating is used to observe light of wavelength 400 nm. The light illuminates 100 slits of the grating. What is the minimum wavelength difference that can be resolved when the second order of diffraction is viewed? *[1 mark]*

A. 1 nm

B. 2 nm

C. 4 nm

D. 8 nm

14. A single-slit diffraction experiment is performed using light of different colours. The width of the central peak in the diffraction pattern is measured for each colour. What is the order of the colours that corresponds to increasing widths of the central peak? *[1 mark]*

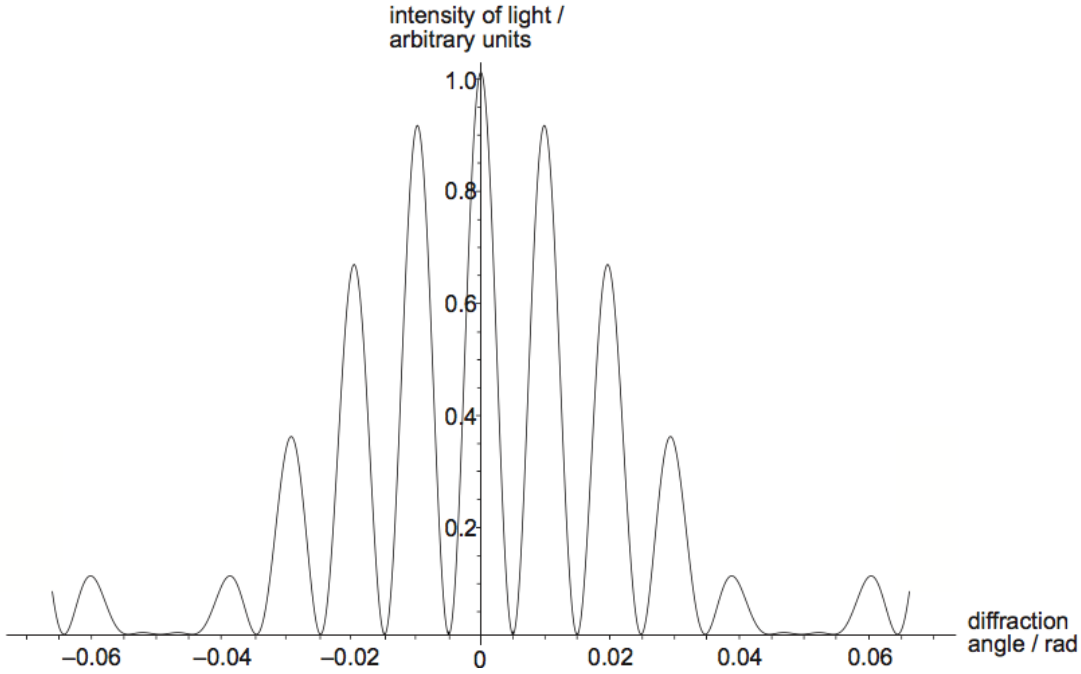
A. red, green, blue

B. red, blue, green

C. blue, green, red

D. green, blue, red

15. In a double-slit interference experiment, the following intensity pattern is observed for light of wavelength λ. *[1 mark]*



The distance between the slits is *d*. What can be deduced about the value of the ratio $\frac{\lambda}{d}$ and the effect of single-slit diffraction in this experiment?

	$\frac{\lambda}{d}$	Single-slit diffraction
A.	100	non-negligible
B.	0.01	non-negligible
C.	100	negligible
D.	0.01	negligible

16. Which of the following experiments provides evidence for the existence of matter waves? *[1 mark]*

A. Scattering of alpha particles

B. Electron diffraction

C. Gamma decay

D. Photoelectric effect

17. A radio telescope has a circular collecting dish of diameter 5.0 m. It is used to observe two distant galaxies that are both emitting electromagnetic radiation of wavelength 20 cm. The images of the galaxies are just resolved by the telescope. What is the angle subtended by the galaxies at the telescope? *[1 mark]*

A. 0.05 rad

B. 0.3 rad

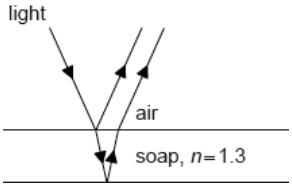
C. 5 rad

D. 30 rad

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.

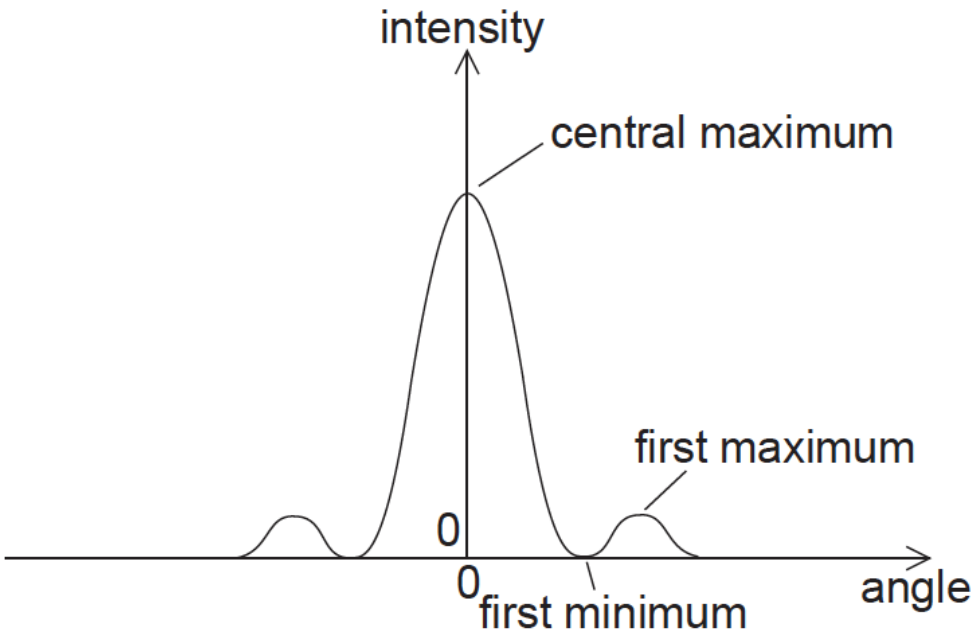


18a. Calculate the wavelength of the light within the soap solution. *[1 mark]*

18b. Calculate the minimum thickness of the soap film that results in constructive interference for the reflected light. *[1 mark]*

18c. Without a calculation, explain why a soap film that is twice as thick as that calculated in (b) results in destructive interference. *[2 marks]*

19. 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.

20. 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]*

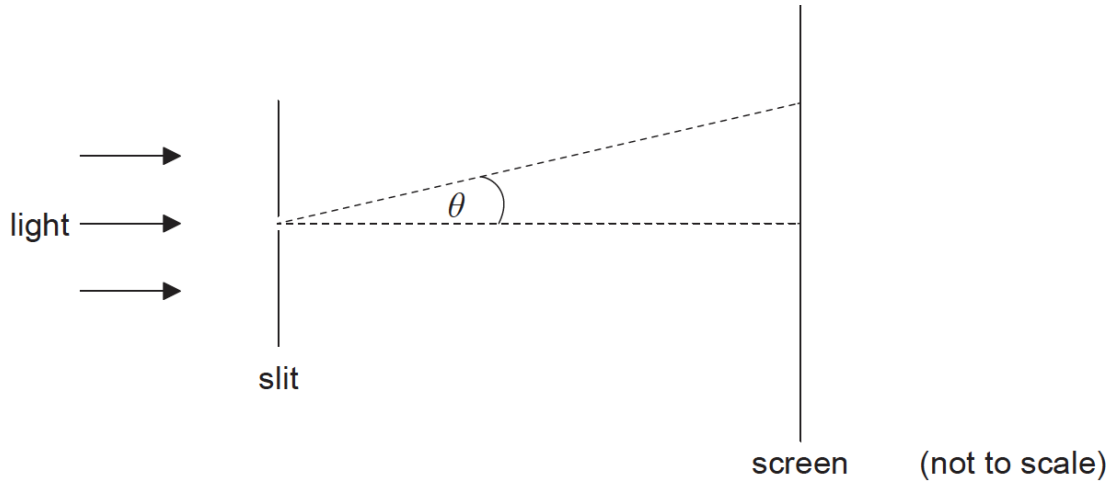
A. Replacing the narrow slit with a circular aperture of same size.

B. Moving the two sources further from the aperture.

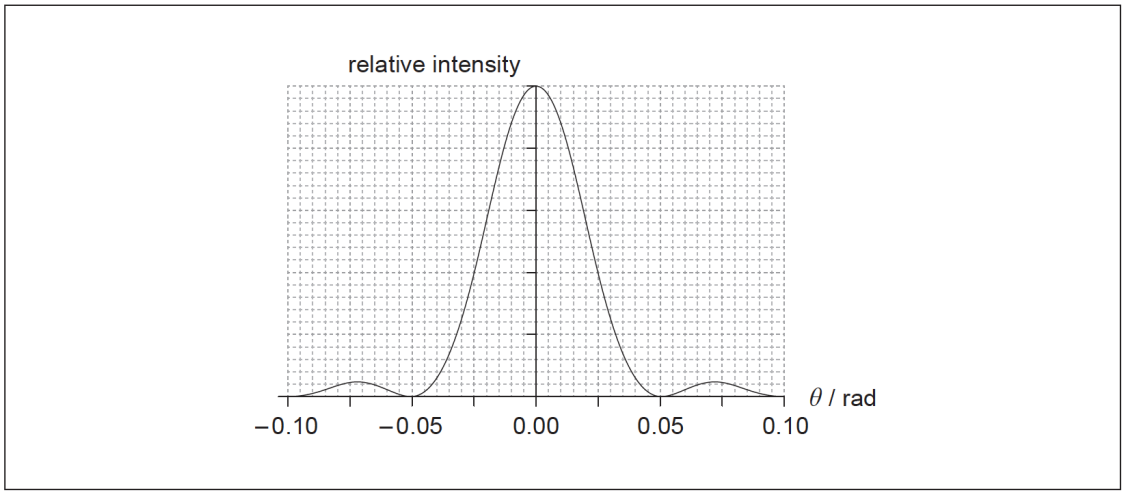
C. Using red light.

D. Using violet light.

This question is about diffraction and resolution.
Monochromatic light is incident on a narrow rectangular slit.



The light is observed on a screen far from the slit. The graph shows the variation with angle θ of the relative intensity for light of wavelength 7.0×10^{-7}m.



21a. Estimate the width of the slit. *[2 marks]*

21b. On the graph, sketch the variation of the relative intensity with θ when the wavelength of the light is reduced. *[1 mark]*

21c. State and explain, with reference to your sketch in (b), whether it is easier to resolve two objects in blue light **or** in red light. *[2 marks]*

22. Radiation is incident on a single rectangular slit. The diffracted beam that emerges from the slit is incident on a screen. The slit width is then doubled and the wavelength of the radiation is also doubled. The intensity of the radiation remains the same. *[1 mark]*

Which of the following correctly describes the angular width of the central maximum of the diffracted beam and the total number of photons incident every second on the screen?

	Angular width of the central maximum	Number of photons incident every second on the screen
A.	unchanged	unchanged
B.	changed	unchanged
C.	unchanged	changed
D.	changed	changed

23. A parallel beam of coherent light of wavelength λ is incident on a rectangular slit of width d. After passing through the slit the light is incident on a screen a distance D from the slit where D is much greater than d. What is the width of the central maximum of the diffraction pattern as measured on the screen? *[1 mark]*

A. $\frac{2D\lambda}{d}$

B. $\frac{2d}{D\lambda}$

C. $\frac{D\lambda}{d}$

D. $\frac{d}{D\lambda}$

This question is about interference.

Light from a laser is incident on two identical parallel slits. The light from the two slits produces a fringe pattern on a screen.

A central bright fringe is produced at C. The next bright fringe is produced at A. There is a dark fringe at B.

The light from the laser is coherent and monochromatic.

24a. Outline what is meant by the term *[2 marks]*

(i) coherent.

(ii) monochromatic.

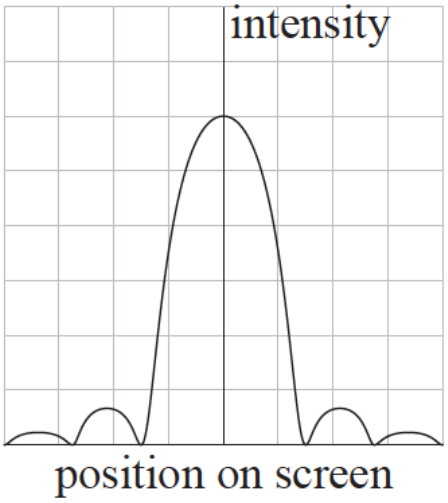
24b. State the phase difference between the light waves from the two slits that meet at B. *[1 mark]*

The distance from the two slits to the screen is 1.5 m. The distance BC is 1.8 mm and the distance between the slits is 0.30 mm.

24c. (i) Show that the laser produces light of wavelength equal to 720 nm. *[4 marks]*

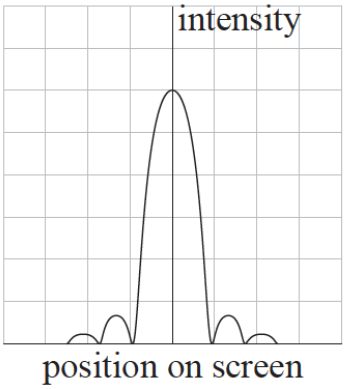
(ii) State the path difference, in metres, between the waves that meet at B.

25. The intensity distribution of monochromatic light passing through a narrow slit and then incident on a screen is shown below. *[1 mark]*

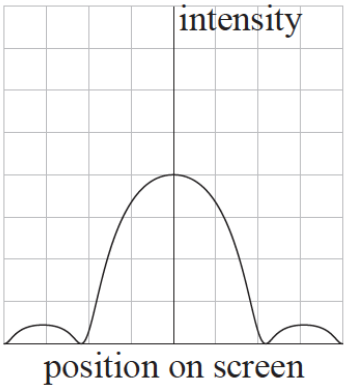


When the slit width is reduced which diagram shows the new intensity distribution? Diagrams are drawn to the same scale as the original.

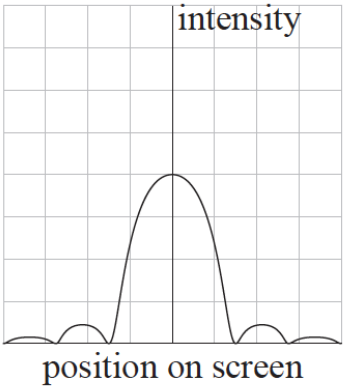
A.



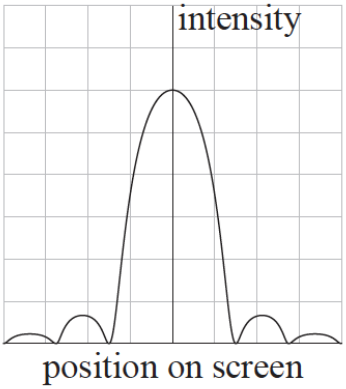
B.



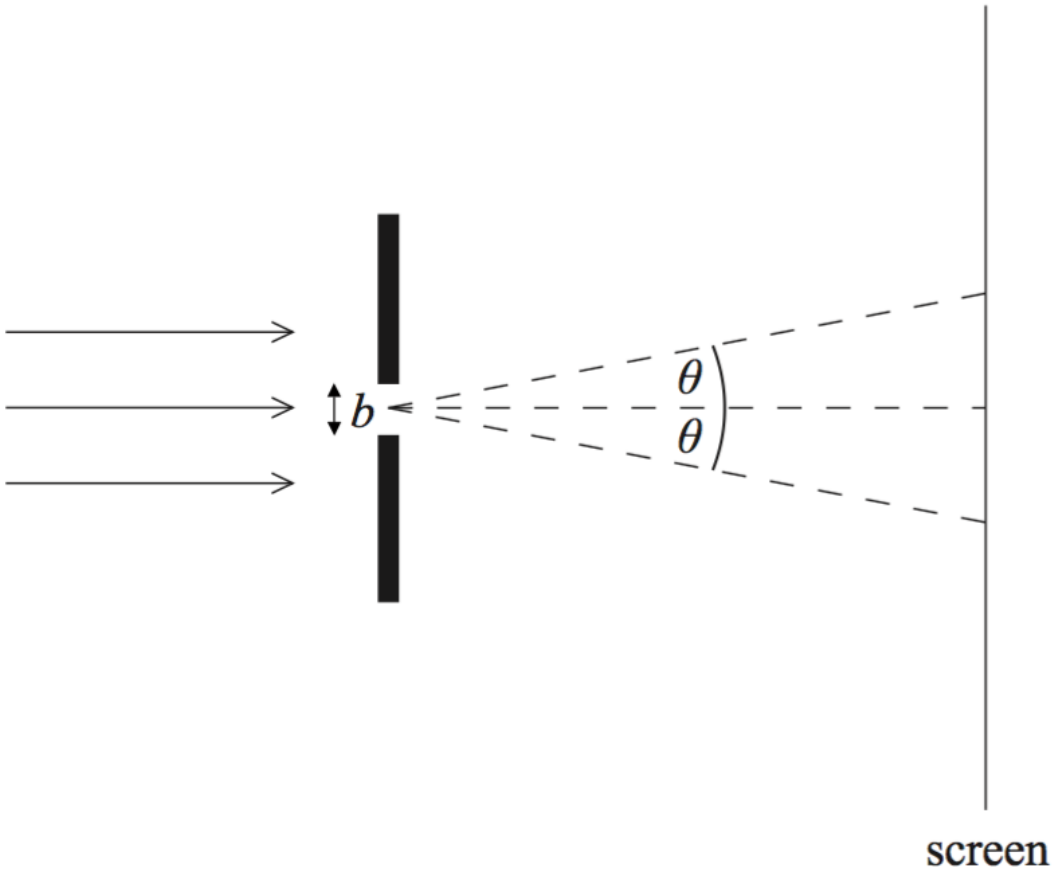
C.



D.



26. A parallel beam of monochromatic light of wavelength λ passes through a slit of width b and forms a diffraction pattern on a screen far from the slit. The angle at which the first diffraction minimum is formed is θ. *[1 mark]*



Which of the following changes in λ and b, carried out separately, will increase the value of θ?

	λ	b
A.	decrease	increase
B.	increase	increase
C.	decrease	decrease
D.	increase	decrease

27. Two coloured point sources are observed through an optical telescope. Which of the following colours for the sources would best allow their images to be resolved? *[1 mark]*

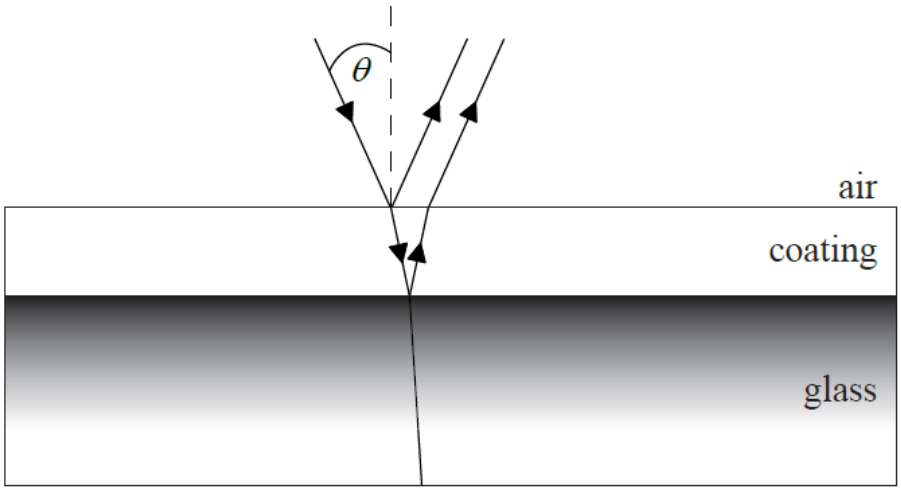
A. Blue
B. Green
C. Red
D. Yellow

28. An optical instrument is used to observe an object illuminated with monochromatic light. Which of the following changes to the frequency of the light and to the aperture diameter of the optical instrument will increase the resolution of the image of the object formed by the instrument? *[1 mark]*

	Frequency	Aperture diameter
A.	increase	decrease
B.	decrease	decrease
C.	increase	increase
D.	decrease	increase

This question is about thin-film interference.

The anti-reflective coating of a lens consists of a thin layer of a suitable material placed between the air and the glass of the lens.



The following data are available.

Refractive index of air = 1.0
Refractive index of coating = 1.2
Refractive index of glass = 1.5

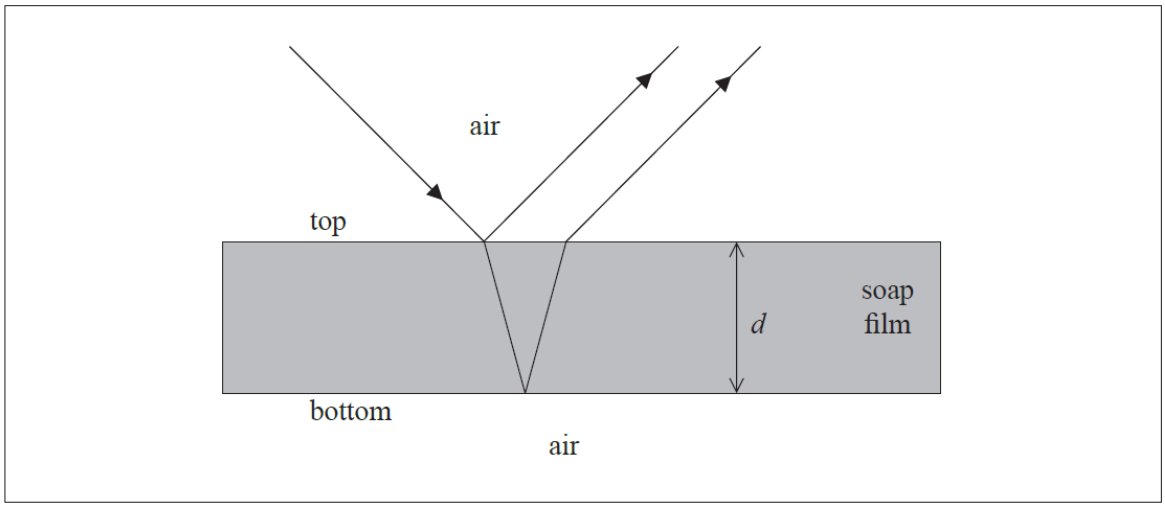
29a. State what phase change occurs on reflection at the air-coating boundary and at the coating-glass boundary. *[1 mark]*

29b. The thickness *d* of the coating layer is 110 nm. *[3 marks]*

Determine the wavelength for which there is no resultant reflection from the surface of the lens for light at normal incidence *($\theta = 0^{o}$)*.

This question is about thin-film interference.

30a. A ray of monochromatic light is incident on a thin film of soap water that is suspended in air. The diagram shows the reflection of this ray from the top and bottom surfaces of the film. *[1 mark]*



On the diagram, label, with the letter P, the point at which a phase difference of π occurs.

30b. White light is incident normally on the soap film. The thickness d of the soap film is 225 nm and its refractive index is 1.34. *[4 marks]*

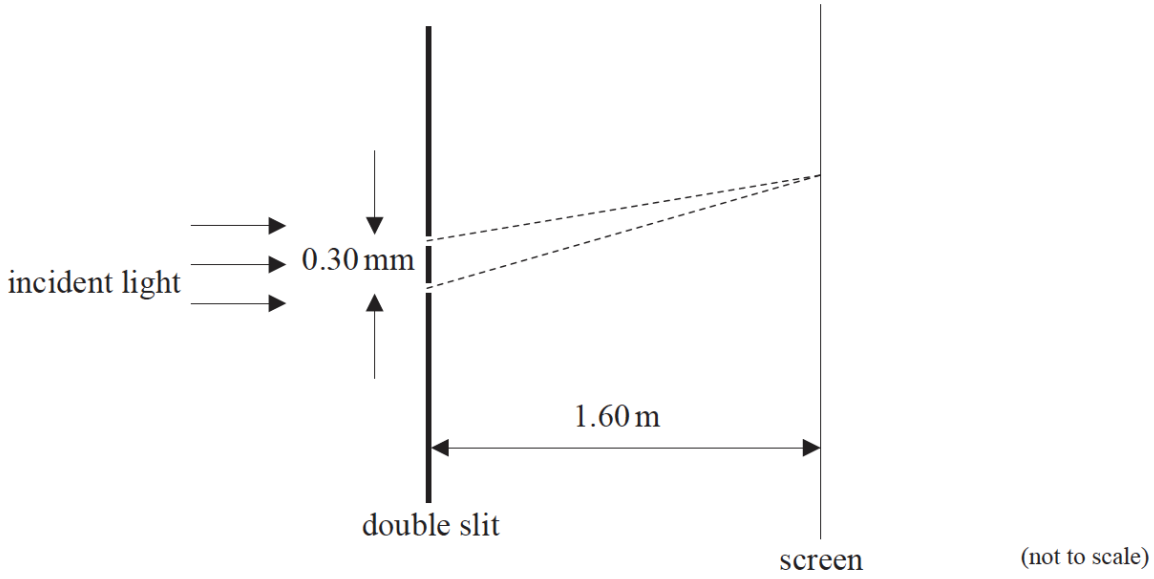
(i) Show that the longest wavelength of light λ in air for which the reflected rays destructively interfere is 603 nm.

(ii) Explain why the soap film will appear coloured.

This question is about interference of light at two parallel slits.

31a. State the condition necessary to observe interference between two light sources. *[1 mark]*

31b. The diagram below shows an arrangement for observing a double slit interference pattern. A parallel beam of coherent light of wavelength 410 nm is incident on two parallel narrow slits separated by 0.30 mm. A screen is placed 1.60 m beyond the slits. *[2 marks]*



Calculate the fringe spacing on the screen.

31c. The slits in (b) are replaced by a large number of slits of the same width and separation as the double slit. Describe the effects that this change will have on the appearance of the fringes on the screen. *[3 marks]*

32. Which of the following would be diffracted the most when incident on a slit of width 1 cm? *[1 mark]*

A. microwaves

B. red light

C. ultraviolet

D. X-rays

33. Two point sources of light have an angular separation of θ, as measured by a distant observer. The light passes through a circular aperture of radius r just before reaching the observer. Which of the following conditions must be true for the two sources to be resolved? *[1 mark]*

A. $\theta < 0.61\frac{\lambda}{r}$

B. $\theta < 1.22\frac{\lambda}{r}$

C. $\theta \geq 0.61\frac{\lambda}{r}$

D. $\theta \geq 1.22\frac{\lambda}{r}$

34. A coherent beam of light of wavelength λ is incident on a double slit. The width of the slits is small compared to their separation. An interference pattern is observed on a distant screen. O is the mid point of the screen. *[1 mark]*

There is a bright fringe at O and a bright fringe at P. Between O and P there are three dark fringes.

Which of the following is the path difference between the light from the two slits arriving at P?

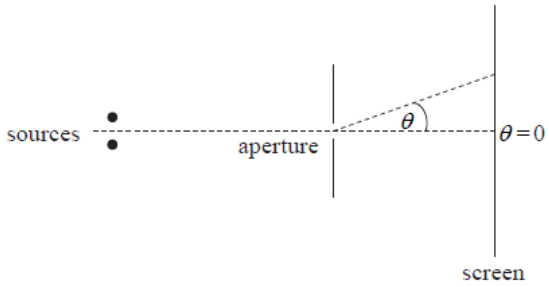
A. 1.5 λ
B. 2 λ
C. 3 λ
D. 4 λ

35. An object to be viewed by a microscope is irradiated with blue light. The reason for using blue light rather than light of a longer wavelength is to increase *[1 mark]*

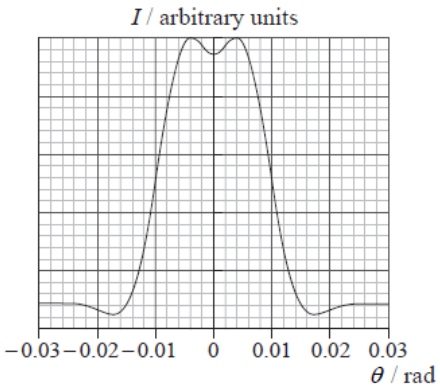
A. diffraction.
B. interference.
C. resolution.
D. magnification.

This question is about resolution.

Light from two monochromatic point sources passes through a circular aperture and is observed on a screen.



The graph shows how the intensity I of the light on the screen varies with the angle θ.



The two sources are just resolved according to the Rayleigh criterion.

36a. State what is meant by resolved in this context. *[1 mark]*

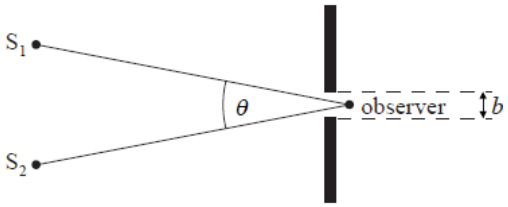
36b. The wavelength of the light from the two sources is 528 nm. The distance of the two sources from the aperture is 1.60 m. *[3 marks]*

Using data from the graph opposite, determine the

(i) separation of the two sources.

(ii) diameter of the aperture.

37. Light of wavelength λ is emitted by two point sources. The light passes through a circular aperture of diameter b and is received by an observer. The angular separation of the sources from the observer's position is θ. The sources are **not** resolved by the observer. *[1 mark]*
Which of the following mathematical relationships applies?



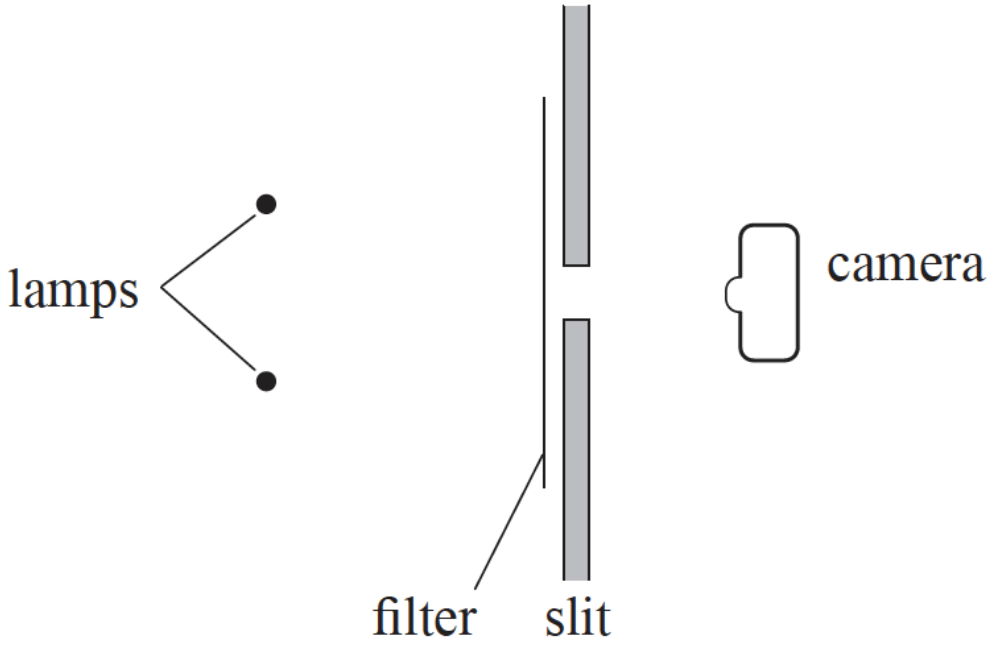
A. $\theta < 1.22\frac{\lambda}{b}$

B. $\theta > 1.22\frac{\lambda}{b}$

C. $\theta = 1.22\frac{\lambda}{b}$

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

38. The diagram below shows two identical filament lamps separated by a small distance. Light from the lamps is incident on a narrow slit behind a green filter. The slit is parallel to the filament of each lamp. A photograph is taken of the lamps through the slit. The images of the filaments on the photograph are just resolved. *[1 mark]*



The green filter is replaced by a red filter and then by a violet filter. For each filter a photograph is taken of the lamps through the slit. Which of the following correctly describes the resolution of the images using a red and using a violet filter?

	Red filter	Violet filter
A.	resolved	resolved
B.	resolved	not resolved
C.	not resolved	resolved
D.	not resolved	not resolved

This question is about using a diffraction grating to view the emission spectrum of sodium.

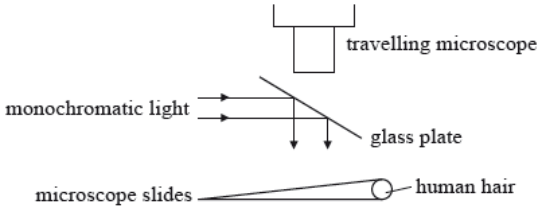
Light from a sodium discharge tube is incident normally upon a diffraction grating having 8.00×10^5 lines per metre. The spectrum contains a double yellow line of wavelengths 589 nm and 590 nm.

39a. Determine the angular separation of the two lines when viewed in the second order spectrum. *[4 marks]*

39b. State why it is more difficult to observe the double yellow line when viewed in the first order spectrum. *[1 mark]*

This question is about thin-film interference.

The diagram (not to scale) represents an experimental set-up designed to measure the diameter of a human hair.



A hair is used to separate two microscope slides. A monochromatic beam of light is reflected onto the two slides by the glass plate. The light is then reflected from the two slides and transmitted through the glass plate and is viewed by the travelling microscope.

40a. State why the light reflected from the two microscope slides produces a system of interference fringes. *[1 mark]*

40b. The condition that a bright fringe is observed in the field of view of the travelling microscope is given by the relationship *[1 mark]*

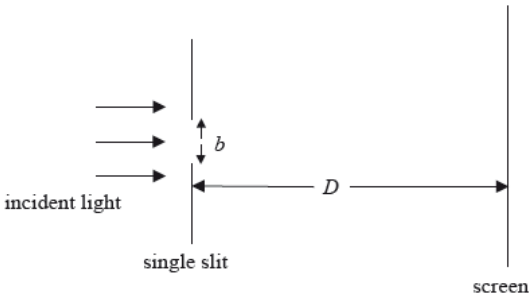
$$2t = \left(m + \frac{1}{2}\right)\lambda$$

where t is the thickness of the air film formed by the wedge at the point where the bright fringe is observed, m is an integer and λ is the wavelength of the incident light.

State the reason for the factor $\frac{1}{2}$ in the relationship.

40c. In the diagram, the length of the slides is 5.00 cm. The wavelength of the monochromatic light is $5.92 \times 10^{-7}\,\text{m}$. Using the travelling microscope it is observed that 50 fringes occupy a length of 0.940 cm. Show that the diameter of the hair used to separate the slides is about $80\ \mu\text{m}$. *[3 marks]*

41. A beam of coherent light is incident on a single slit of width b. After passing through the slit, the light is incident on a screen at a distance D from the slit. *[1 mark]*



Which of the following changes, carried out separately, in respect of b and D will result in an increase in width of the first diffraction maximum formed on the screen?

	b	D
A.	decrease	increase
B.	increase	increase
C.	decrease	decrease
D.	increase	decrease

42. The images of two sources are just resolved. Which of the following is a correct statement of the Rayleigh criterion for this situation? *[1 mark]*

A. The central maximum of the diffraction pattern of one source must coincide with the central maximum of the diffraction pattern of the other source.

B. Light from the sources must pass through a circular aperture.

C. Light from the sources must be coherent.

D. The first minimum of the diffraction pattern of one source must coincide with the central maximum of the diffraction pattern of the other source.

43. Two galaxies with an angular separation at the observer of 5.0×10^{-4} radians are observed with a radio telescope. Both galaxies emit radio waves of wavelength $2.5 \times 10^{-2}\,\text{m}$. *[1 mark]*

The images of the galaxies are just resolved by the telescope. The diameter of the circular collecting dish of the telescope is

A. 61 m.

B. 50 m.

C. 30 m.

D. 25 m.

44. A parallel beam of monochromatic light of wavelength λ passes through a slit of width b. After passing through the slit the light is incident on a distant screen. The angular width of the central maximum is *[1 mark]*

A. $2\frac{\lambda}{b}$ radians.

B. $\frac{\lambda}{b}$ radians.

C. $2\frac{\lambda}{b}$ degrees.

D. $\frac{\lambda}{b}$ degrees.