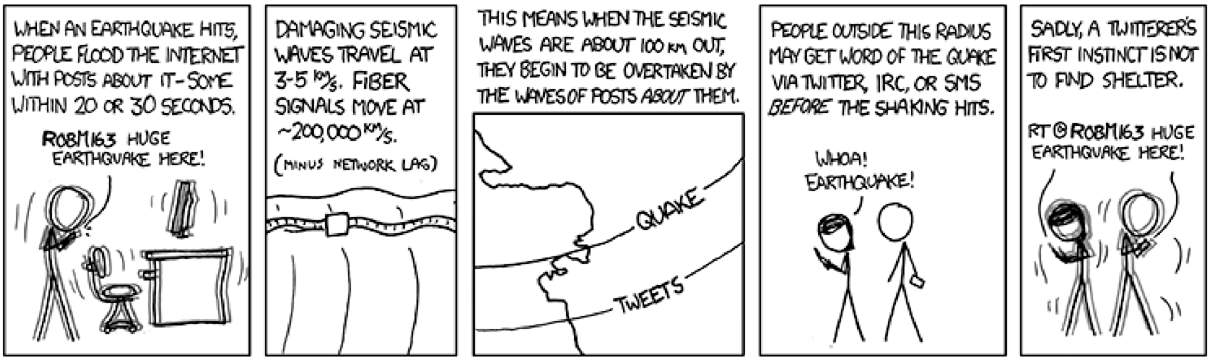
Advanced Higher Physics

Past Paper Questions

2.5 Interference



10. The internal structure of some car windscreens produces an effect which can be likened to that obtained by slits in a grating.

A passenger in a car observes a distant red traffic light and notices that the red light is surrounded by a pattern of bright spots.

This is shown in Figure 10A.

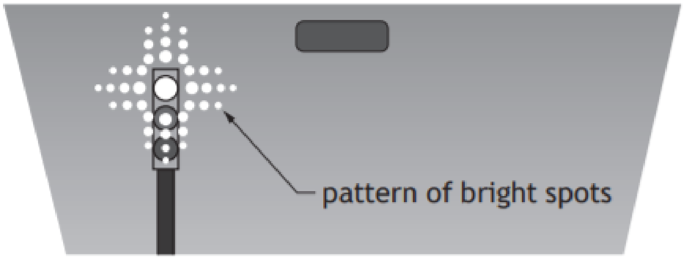


Figure 10A

(a) Explain how the **two-dimensional** pattern of bright spots shown in Figure 10A is produced. **2**

(b) The traffic light changes to green. Apart from colour, state a difference that would be observed in the pattern of bright spots.

Justify your answer. **2**

(c) An LED from the traffic light is tested to determine the wavelength by shining its light through a set of Young's double slits, as shown in Figure 10B.

The fringe separation is $(13{\cdot}0 \pm 0{\cdot}5)$ mm and the double slit separation is $(0{\cdot}41 \pm 0{\cdot}01)$ mm.

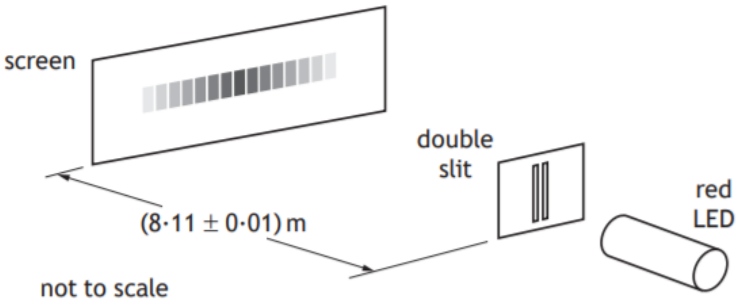


Figure 10B

(i) Calculate the wavelength of the light from the LED. **3**

(ii) Determine the absolute uncertainty in this wavelength. **5**

(iii) The experiment is now repeated with the screen moved further away from the slits.

Explain why this is the most effective way of reducing the uncertainty in the calculated value of the wavelength. **1**

8. A beam of electrons is incident on a grating as shown in Figure 8A.

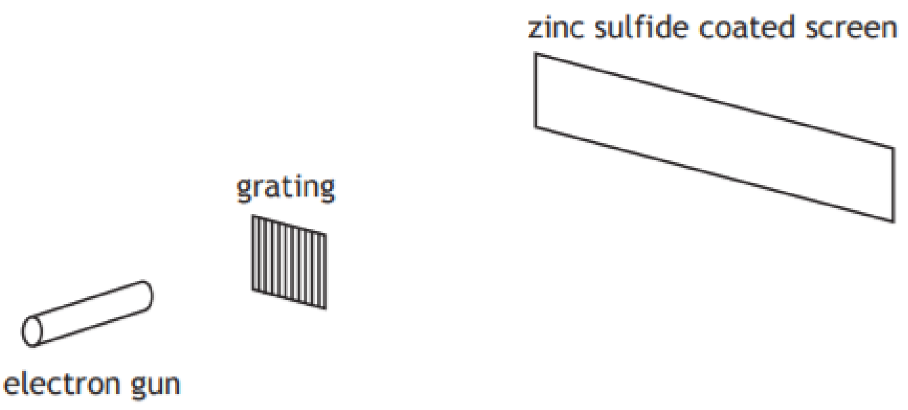


Figure 8A

(a) After passing through the grating the electrons are incident on a zinc sulfide coated screen. The coating emits light when struck by electrons.

Describe the pattern observed on the screen. **1**

(b) Scientists perform similar experiments with large molecules. One such molecule is buckminsterfullerene (C60) with a mass of $1{\cdot}20 \times 10^{-24}$ kg.

For C60 molecules with a velocity of $220\,\text{m s}^{-1}$ estimate the slit spacing required to produce a pattern comparable to that observed for the electrons. You must justify your answer by calculation. **4**

Marks

8. A student carries out a Young's double slit experiment in order to determine the wavelength of monochromatic red light.

The student uses the apparatus shown in Figure 8 to produce an interference pattern on the screen.

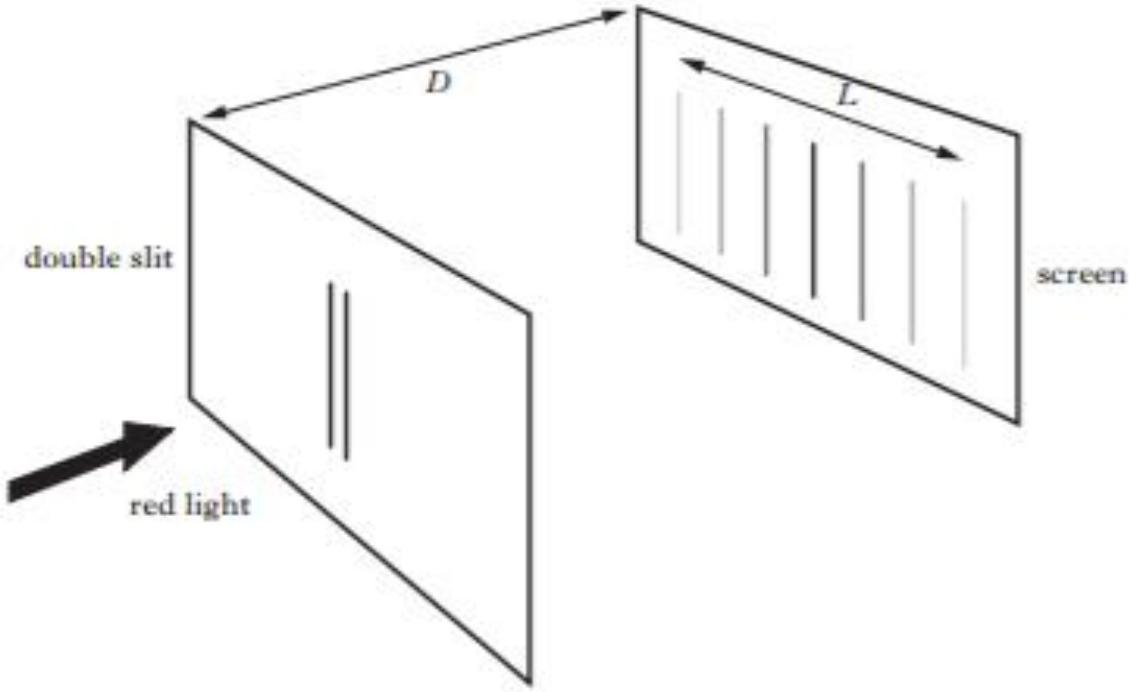


Figure 8

The double slit separation d is measured using a travelling microscope. The distance D between the double slit and the screen is measured using a steel measuring tape. The length L of the interference pattern is measured using a plastic ruler.

The student records the following data.

$D = (4{\cdot}250 \pm 0{\cdot}005)$ m
$L = (67 \pm 2)$ mm
$d = (0{\cdot}25 \pm 0{\cdot}01)$ mm

(*a*) (i) State why it is possible to produce an interference pattern using only a single light source. **1**

(ii) Calculate the wavelength of the light from the source. **3**

(iii) Calculate the absolute uncertainty in the wavelength. **3**

(*b*) The student repeats the experiment with the same apparatus but uses a monochromatic blue light source. D remains fixed.

State the effect this will have on the percentage uncertainty in the calculated value for the wavelength of the blue light.

You must justify your answer. **2**

Marks

9. A series of coloured LEDs are used in the Young's slit experiment as shown in Figure 9. The distance from the slits to the screen is (2·50 ± 0·05)m. The slit separation is $(3 \cdot 0 \pm 0 \cdot 1) \times 10^{-4}$ m.

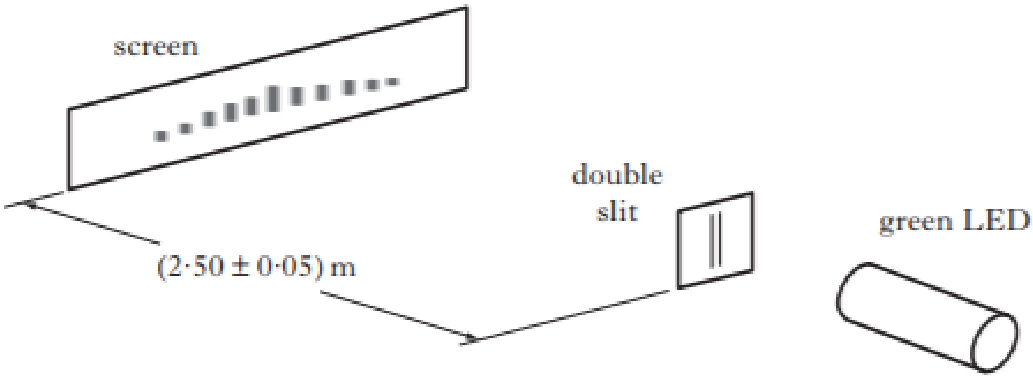


Figure 9

Colour of LED	*Wavelength* (nm)
Red	650 ± 2
Green	510 ± 2
Blue	470 ± 2

(*a*) State whether the pattern on the screen is caused by the division of wavefront or the division of amplitude. **1**

(*b*) (i) Calculate the fringe separation observed on the screen when the green LED is used. **2**

(ii) Calculate the absolute uncertainty in the fringe separation. **3**

(6)

10. (*a*) When sunlight hits a thin film of oil floating on the surface of water, a complex pattern of coloured fringes is observed.

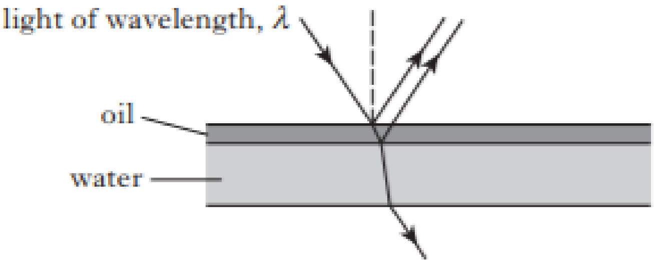


Figure 10

Explain how these fringes are formed. **2**

(*b*) The surface of a lens is coated with a thin film of magnesium fluoride.

Calculate the minimum thickness required to make the lens non-reflecting at a wavelength of 555 nm. **2**

(*c*) The lens of a digital camera appears to be purple in white light.

Explain this observation. **2**

(6)

Mark

8. High quality *optical flats* made from glass are often used to test components of optical instruments. A high quality optical flat has a very smooth and flat surface.

(*a*) During the manufacture of an optical flat, the quality of the surface is tested by placing it on top of a high quality flat. This results in a thin air wedge between the flats as shown in Figure 8A.

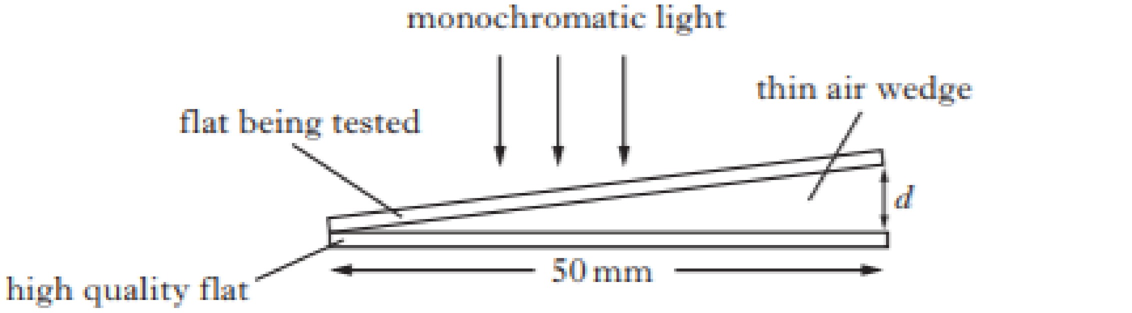


Figure 8A

The thickness d of the air wedge is $6{\cdot}2 \times 10^{-5}$ m.

Monochromatic light is used to illuminate the flats from above. When viewed from above using a travelling microscope, a series of interference fringes is observed as shown in Figure 8B.

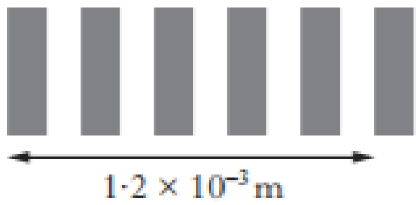
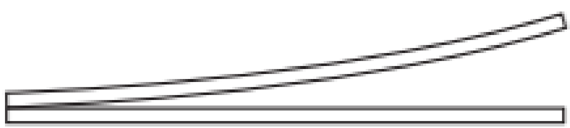


Figure 8B

Calculate the wavelength of the monochromatic light. **3**

(*b*) A second flat is tested using the same method as in part (*a*). This flat is slightly curved as shown in Figure 8C.



(*c*) Good quality optical flats often have a non-reflecting coating of magnesium fluoride applied to the surface as shown in Figure 8D.

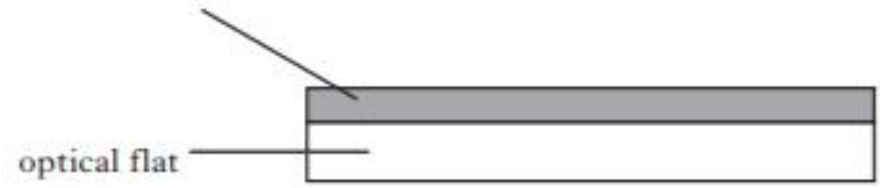


Figure 8D

(i) With the aid of a diagram explain fully how the coating reduces reflections from the flat for monochromatic light. **2**

(ii) Calculate the minimum thickness of magnesium fluoride required to make the flat non-reflecting for yellow light from a sodium lamp. **2**

(8)

Traditional 2012

11. A student uses laser light of wavelength of 529 nm to determine the separation of the slits in a Young's double slit arrangement as shown in Figure 11A.

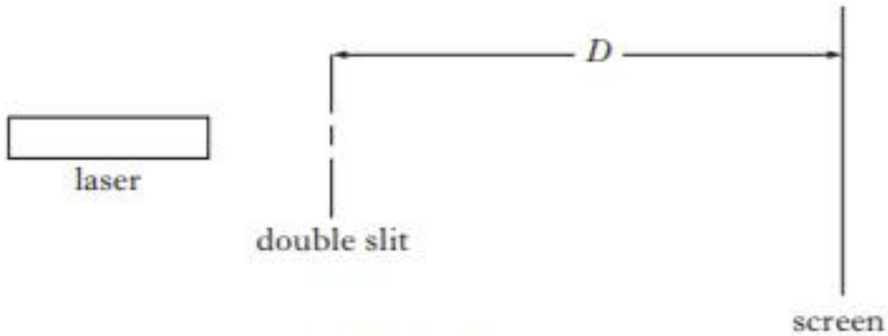


Figure 11A

A pattern of bright green dots is observed on the screen. The distance between the central maximum and the next bright dot is Δx as shown in Figure 11B.

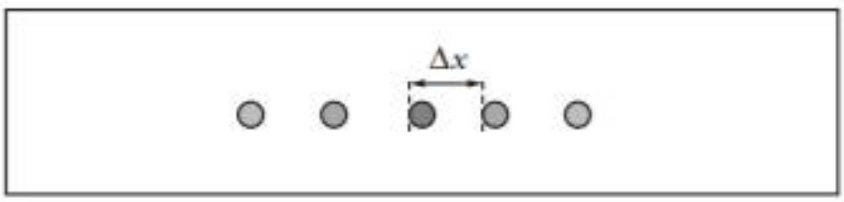


Figure 11B

The distance Δx is measured with a metre stick. The distance D is measured with a tape measure.

The screen is moved and Δx and D are measured for six positions of the screen. Each pair of measurements is repeated five times.

The student uses the results to plot the graph shown in Figure 11C.

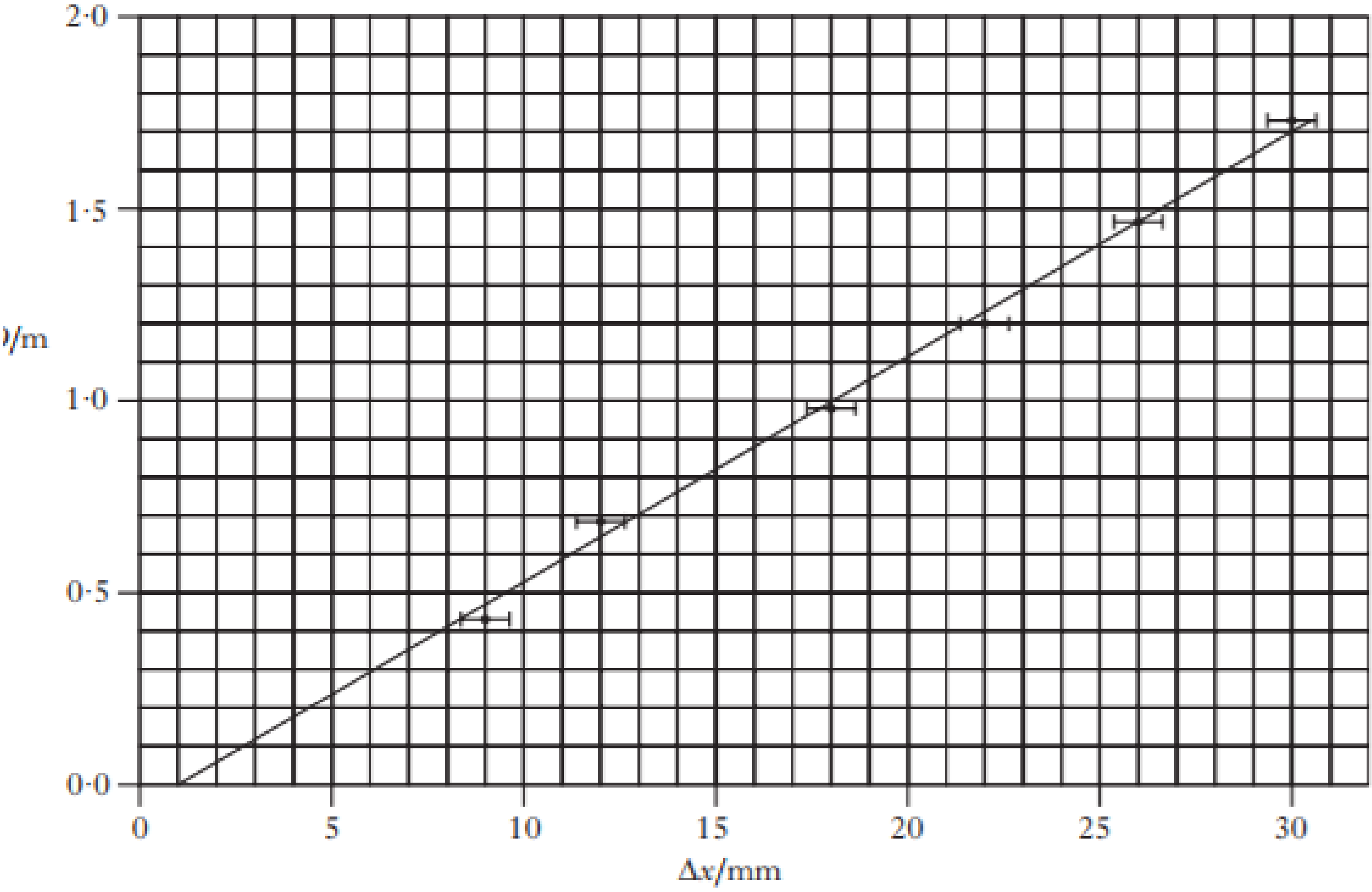


Figure 11C

(*a*) (i) Using the gradient of the graph, calculate the separation of the double slits. **2**

(ii) Suggest a reason why no error bars are shown for the slit to screen distance, D. **1**

(iii) Other than repeating the measurements, suggest **two** improvements to the student's experimental technique. **2**

(*b*) The experiment is repeated using a very bright LED in place of the laser. The LED emits light in the wavelength range 535 to 555 nm.

Other than a slight colour change, state **two** differences in the pattern observed on the screen compared to the pattern shown in Figure 11B. **2**

(7)

9. A laser-based quality control system to measure thread spacing in fabric samples is being evaluated. The 2-dimensional interference pattern is displayed on a screen shown in Figure 9A.

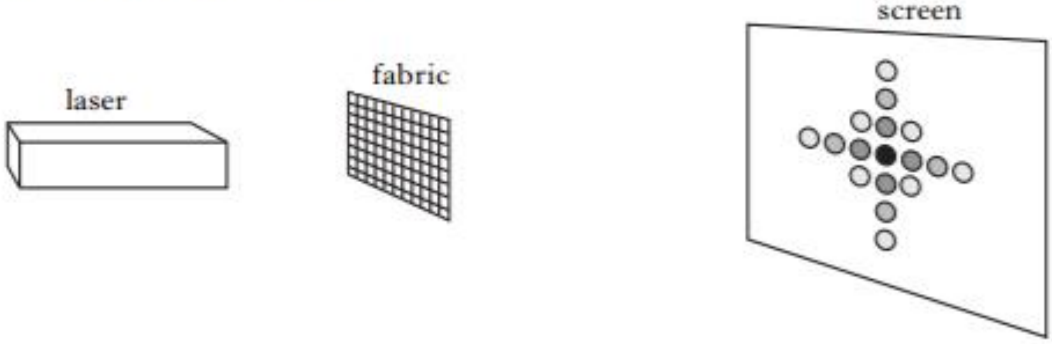


Figure 9A

(*a*) Explain how this 2-D interference pattern is produced. **2**

(*b*) When a fine beam of laser light of wavelength 488 nm is used, the separation of the maxima in the horizontal direction is 8·00 mm. The distance from the fabric sample to the screen is 3·60 m.

Assume the spaces between the threads act like Young's slits.

Calculate the spacing between the threads in the sample. **2**

(*c*) The interference pattern from a standard fabric sample using a 488 nm laser is shown in Figure 9B.

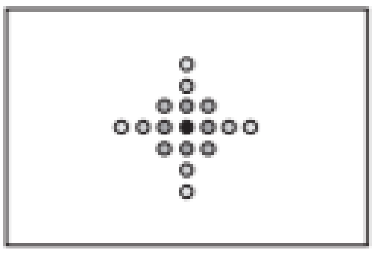
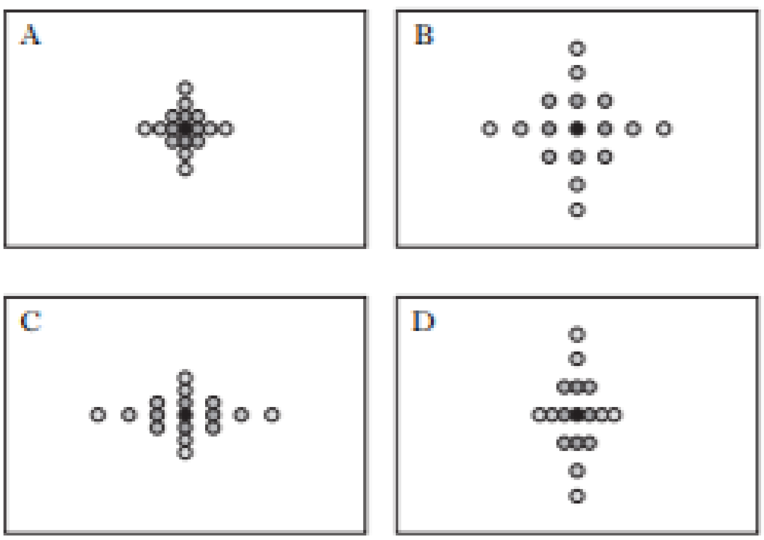


Figure 9B

(i) The 488 nm laser is replaced with a 667 nm laser. Which interference pattern from Figure 9C best represents the new interference pattern? Justify your answer. **2**



(ii) The **original** 488 nm laser is restored and the fabric sample is stretched as shown in Figure 9D.

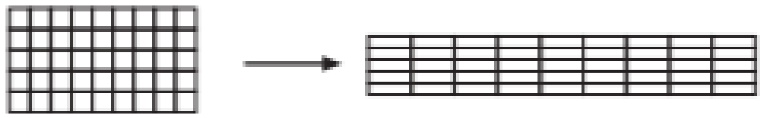


Figure 9D

Which pattern from Figure 9C best represents the new pattern? Justify your answer. **2**

(8)

Traditional 2010

10. (*a*) Explain the formation of coloured fringes when white light illuminates a thin film of oil on a water surface. **2**

(*b*) Thin film coatings deposited on glass can be used to make the glass non-reflecting for certain wavelengths of light, as shown in Figure 10A.

The refractive index of the coating is less than glass, but greater than air.

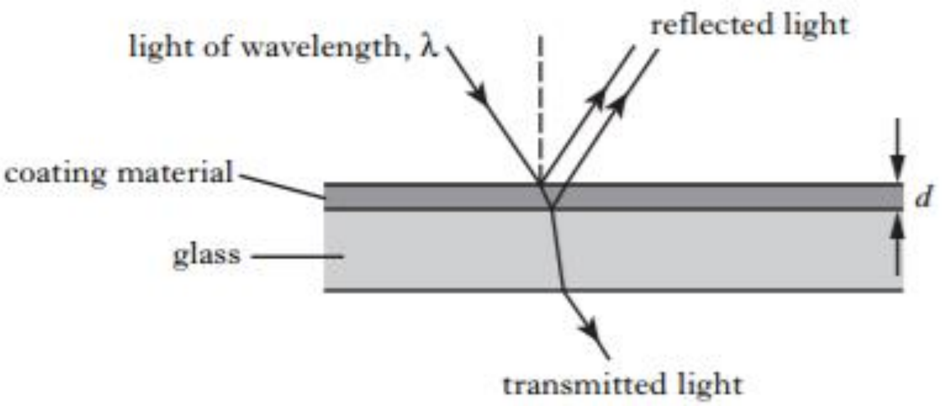


Figure 10A

Show that for near normal incidence

$$d = \frac{\lambda}{4n}$$

where n is the refractive index of the coating material and d is the thinnest coating that will be non-reflecting for light of wavelength, λ. **2**

(*c*) The relationship in (*b*) also applies to radiation of wavelength 780 nm.

A thin film coating has a refractive index of 1·30. For radiation of wavelength 780 nm the minimum thickness for a thin film that is non-reflecting is 0·150 µm. In practice, this thickness is too thin to manufacture.

Calculate the thickness of the next thinnest coating that would be non-reflecting for this wavelength. **2**

9. (*a*) A student is measuring the thickness of a piece of paper using a thin air wedge. The air wedge is formed between two glass plates that are in contact at one end and separated by a sheet of paper at the other end.

Monochromatic light is reflected down onto the air wedge. A travelling microscope is used to view the resulting interference pattern as shown in Figure 9A.

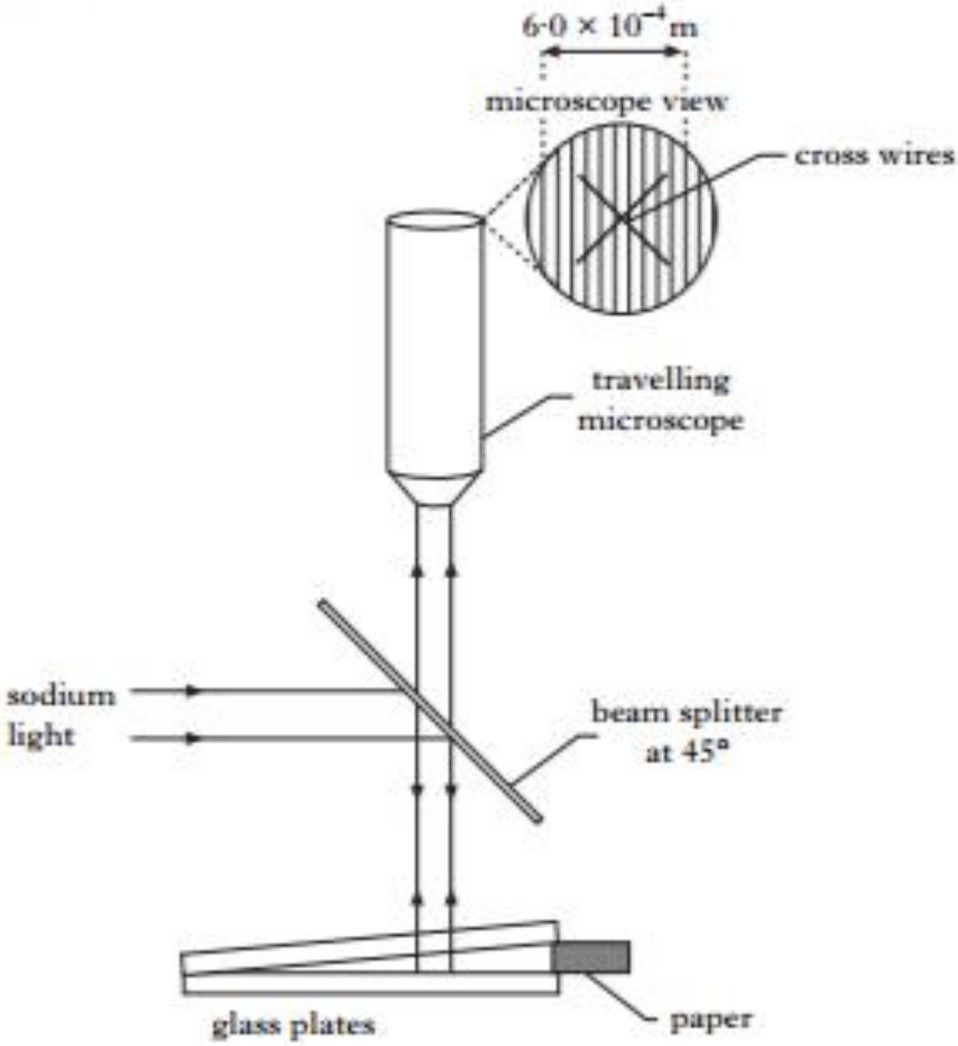


Figure 9A

(i) The air wedge produces interference by division of amplitude.

State what is meant by the term *division of amplitude*. **1**

(ii) The following data is obtained.

10 fringe separations = $(6{\cdot}0 \pm 0{\cdot}5) \times 10^{-4}$ m

Wavelength, λ = 580 nm ± 10 nm

Length of glass plate, $l = (4{\cdot}0 \pm 0{\cdot}1) \times 10^{-2}$ m

Calculate the thickness of the paper. **3**

(iii) Calculate the percentage uncertainty in the thickness. **2**

Marks

9. (continued)

(*b*) A beam of monochromatic light of wavelength 580 nm illuminates a film of soap that is held in a wire loop. An interference pattern is produced as shown in Figure 9B.

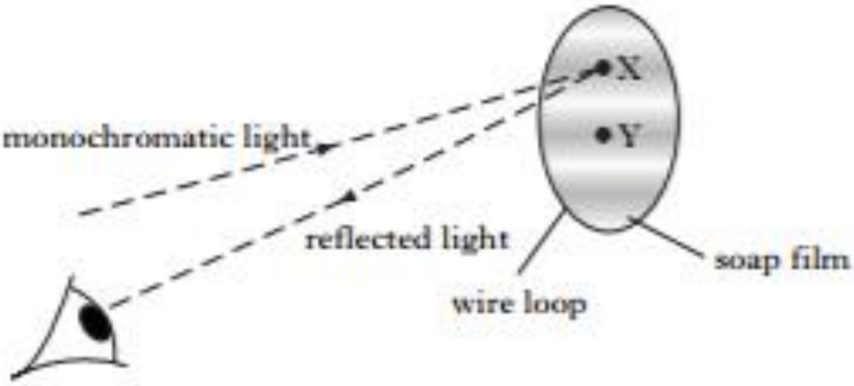


Figure 9B

An expanded view of part of the film is shown in Figure 9C.

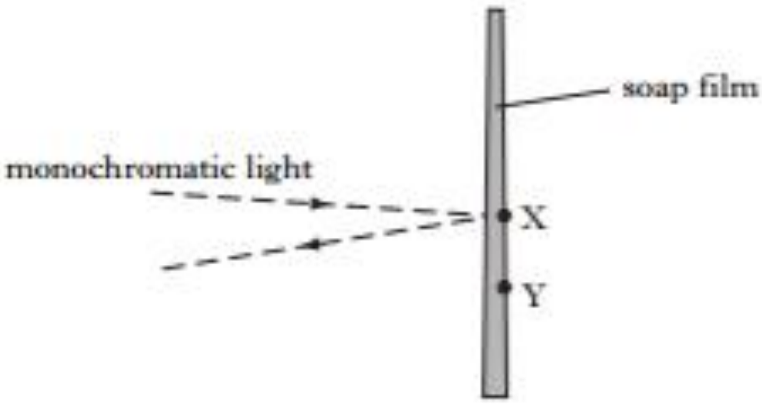


Figure 9C

(i) Destructive interference occurs when light is reflected at position X.

Explain why destructive interference occurs. You may include a diagram as part of your answer. **2**

(ii) At position X the thickness of the film is 4·00 μm.

The refractive index of the film of soap is 1·45.

Calculate the optical path difference produced by this film at position X. **2**

(iii) The **next** position where destructive interference occurs is position Y where the film is slightly thicker.

Calculate the optical path difference produced by the film at position Y. **2**

(12)

Marks

11. Light from a helium-neon laser is incident on a double slit. A pattern of light and dark fringes is observed on a screen 3·50 m beyond the slits as shown in Figure 20.

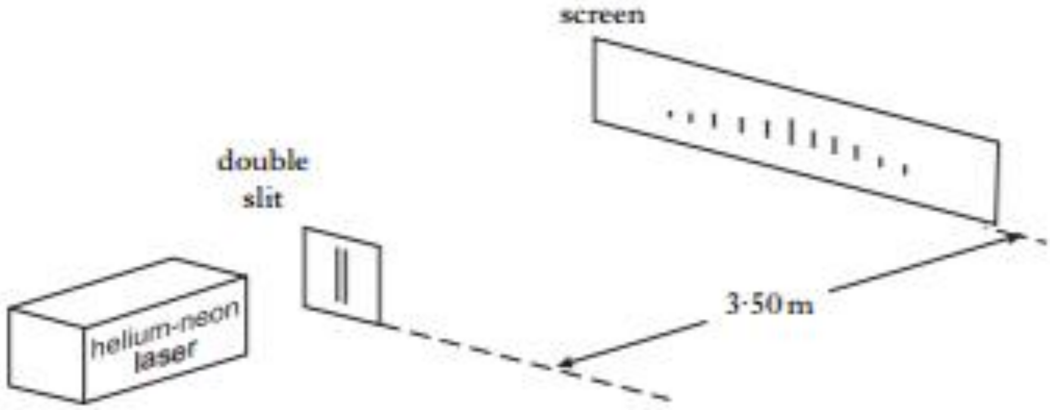


Figure 20

(*a*) State whether these fringes are caused by division of amplitude or division of wavefront. 1

(*b*) The distance between two adjacent bright fringes on the screen is 7·20 mm. Calculate the separation of the two slits. 2

(*c*) The distance between the double slit and screen is increased to 5·50 m. The distance between the fringes is remeasured and the calculation of the slit separation is repeated.

(i) Explain **one** advantage of moving the screen further away from the double slit. 2

(ii) State **one** disadvantage of moving the screen further away from the double slit. 1

(6)

10. (continued)

(*b*) A thin air wedge is formed between two glass plates which are in contact at one end and separated by a thin metal wire at the other end.

Figure 16 shows sodium light being reflected down onto the air wedge. A travelling microscope is used to view the resulting interference pattern.

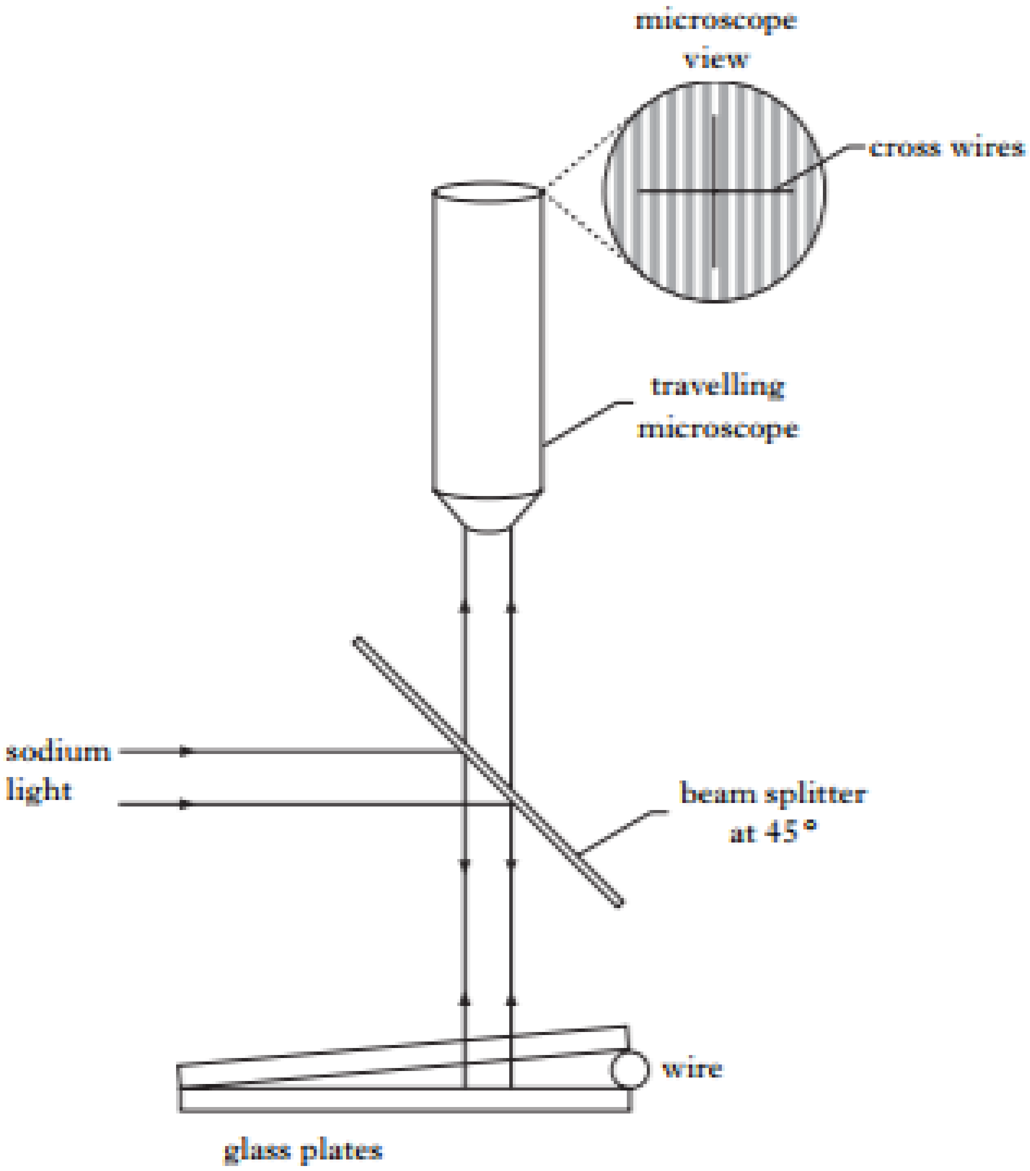


Figure 16

Explain how the diameter of the wire is determined using measurements obtained with this apparatus.

Assume the sodium light is monochromatic.

Your answer should include:

- the measurements required
- any data required
- the equation used. **2**

(8)

Marks

11. (a) An air wedge is formed between two flat glass plates of length l, which are in contact at one end. They are separated by a human hair of diameter d at the other end, as shown in Figure 15.

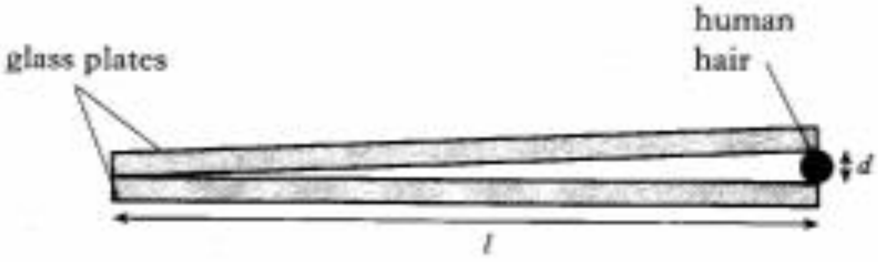


Figure 15

The air wedge is illuminated from above by a monochromatic light source of wavelength λ. When viewed from above a series of interference fringes of separation Δx is observed.

(i) Use this information to derive an expression for the diameter of the human hair. **2**

(ii) The wavelength of the monochromatic light is 589 nm, the length of the glass plates is 75 mm and the separation between two adjacent dark fringes is $3{\cdot}4 \times 10^{-4}$ m.

Calculate the diameter of the hair. **1**

(b) A camera lens can be made non-reflecting by coating it with a thin layer of magnesium fluoride.

(i) Calculate the thickness of magnesium fluoride required to make the lens non-reflecting for light of wavelength 548 nm. **2**

(ii) The lens has a thin film of transparent liquid placed on its surface as shown in Figure 16. The refractive index of the liquid is 1·45.

Figure 16

Explain why the coating is no longer non-reflective. **2**

(c) Explain why coloured fringes can be observed when a thin film of oil forms on a puddle of water. **1**

(8)

Marks

10. A student sets up a Young's slits experiment in order to measure the wavelength of monochromatic light emitted by a laser. The light from the laser passes through a double slit before reaching a screen, where a pattern of light and dark fringes is seen, as shown in Figure 19.

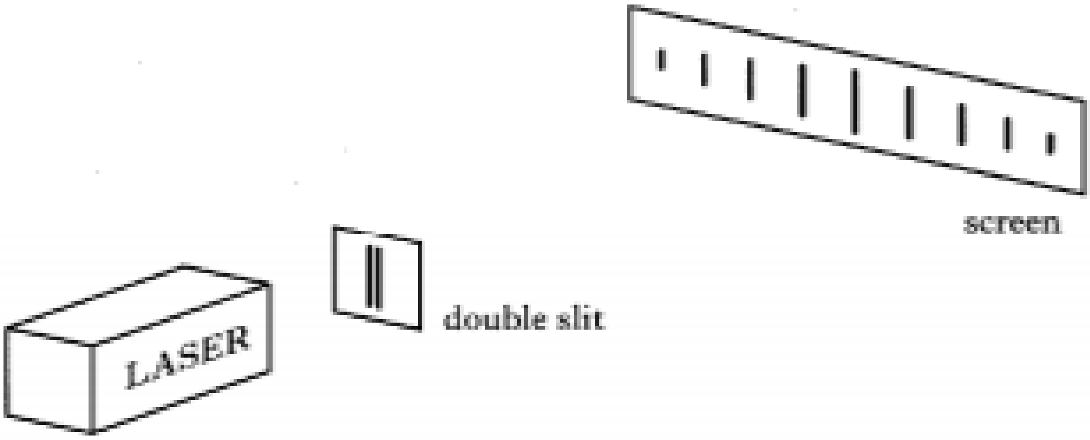


Figure 19

The student records the following measurements:

double slit separation	=	$0{\cdot}25 \pm 0{\cdot}01$ mm
distance between double slits and screen	=	$3{\cdot}91 \pm 0{\cdot}01$ m
distance between two adjacent bright fringes	=	$8{\cdot}0 \pm 0{\cdot}5$ mm.

(*a*) (i) Calculate the wavelength of the laser light. **2**

(ii) Show that the absolute uncertainty in the calculated wavelength is $\pm 4 \times 10^{-8}$ m. **2**

(iii) State why an answer of $\pm 3{\cdot}78 \times 10^{-8}$ m for part (*a*)(ii) would **not** be acceptable. **1**

(*b*) The student now measures the distance between 9 bright fringes (8 spaces). The result is

distance between 9 fringes (8 spaces) = $64{\cdot}0 \pm 0{\cdot}5$ mm.

Calculate the new absolute uncertainty in wavelength, assuming the other measurements remain unchanged. **2**

(*c*) (i) The student then suggests that measuring the distance between 12 bright fringes would significantly reduce the absolute uncertainty in the wavelength. Explain why this is **not** correct. **1**

(ii) State which measurement must be made more accurately to reduce significantly the absolute uncertainty in the wavelength. **1**

(9)

Marks

13. A student sets up a "Young's double slit" experiment, as shown in Figure 18, to measure the wavelength of laser light.

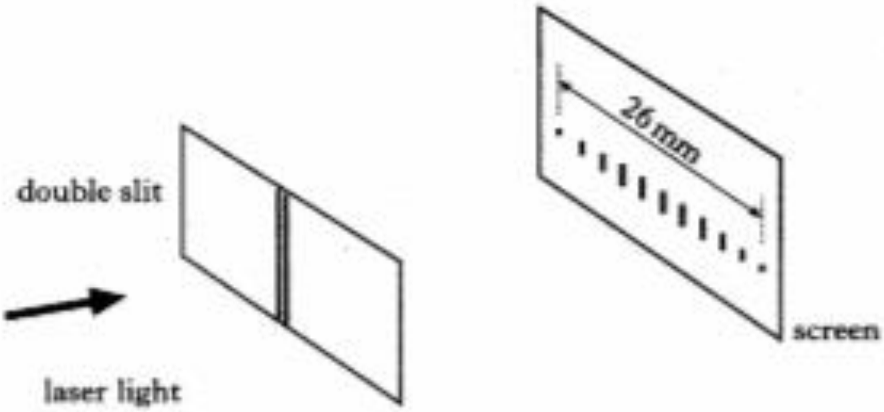


Figure 18

The student obtains the following results.

Separation of 11 fringes	26 (±2) mm
Distance to screen from slits	2·00 (±0·01) m
Separation of slits	0·52 (±0·02) mm

(a) Calculate the wavelength of the laser light. **2**

(b) Calculate the percentage uncertainty in this wavelength. **3**

(c) Suggest an improvement to the experiment that would reduce the uncertainty in the calculated value of the wavelength.
Justify your answer. **2**

(d) Which principle does this experiment illustrate, interference by division of wavefront or by division of amplitude? **1**

(8)

Marks

11. (*a*) (i) State the condition for two light sources to be coherent.

(ii) Monochromatic light is directed towards a glass slide as shown in Figure 19. The glass has a refractive index of 1·4.

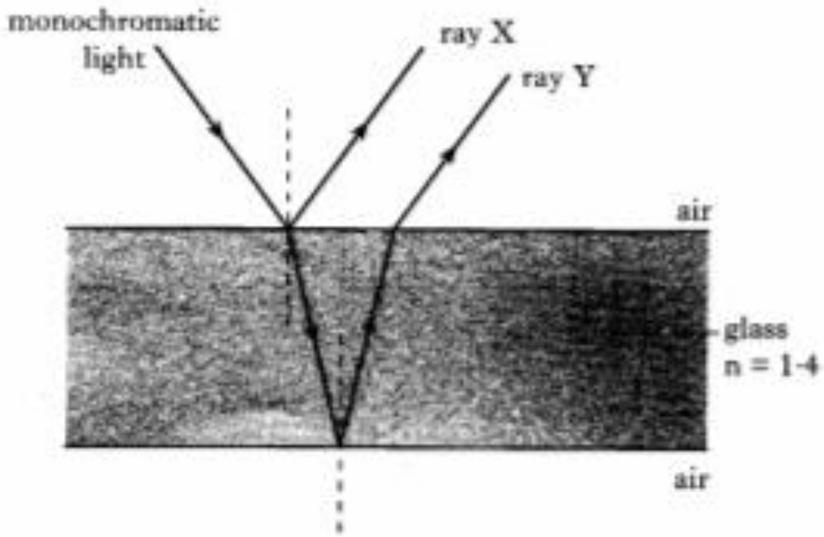


Figure 19

Ray Y has travelled further than ray X.

State the relationship between the path difference and the **optical** path difference between the rays.

(iii) In terms of optical path difference, state the conditions for:

(A) constructive interference of rays X and Y;

(B) destructive interference of rays X and Y.

(iv) A glass slide, set up as shown in Figure 19, is observed at near normal incidence. Constructive interference is observed.

The glass slide is now placed on the surface of a liquid of refractive index greater than 1·4. Destructive interference is now observed at near normal incidence.

Explain this observed change. **4**

(*b*) Good quality lenses reflect very little light.

A thin coating of magnesium fluoride on the surface of a lens reduces reflection.

(i) Explain briefly why this coating reduces reflection.

(ii) Calculate the thickness of magnesium fluoride that minimises reflection for light of wavelength 550 nm. **3**

(7)

Marks

11. (a) (i) Explain, **with the aid of a diagram**, how a thin coating on the surface of a camera lens can make it non-reflecting for monochromatic light at near normal incidence.

(ii) Calculate the thickness of a layer of magnesium fluoride required to make the surface of a lens non-reflecting for light of wavelength 500 nm.

(iii) When white light is incident upon a lens with this coating, a purple hue is observed in the reflected light. Explain how this colour effect is produced. **6**

(b) Light from a red laser is incident upon a double slit which has a slit separation of $5{\cdot}0 \times 10^{-5}$ m. A screen is placed 2·0 m beyond the double slit as shown in Figure 9.

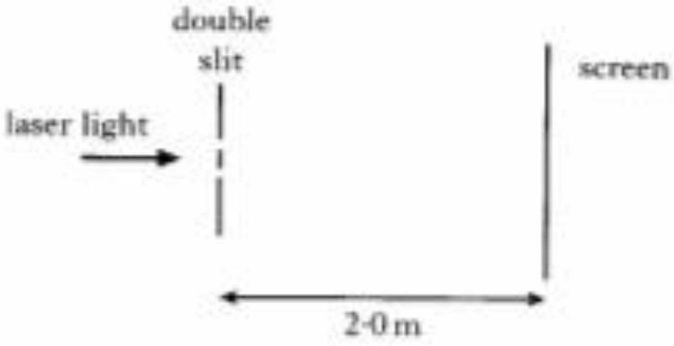


Figure 9

A pattern of light and dark fringes, as shown in Figure 10, is observed on the screen.

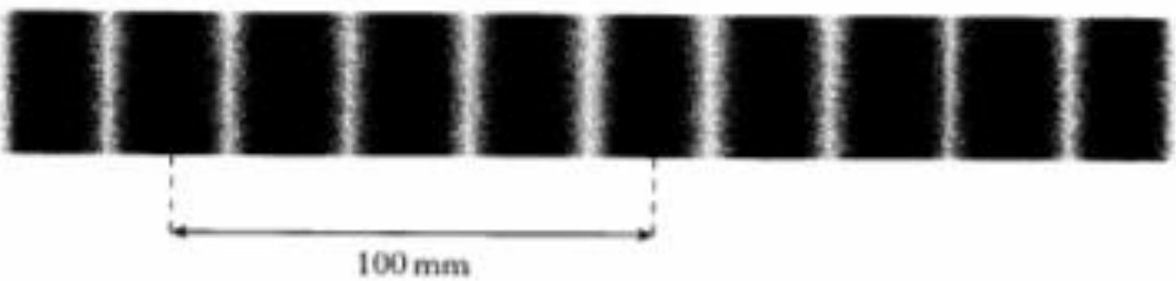


Figure 10

Calculate the wavelength of the laser light. **3**

(9)

Marks

10. A thin air wedge is formed between two flat glass plates which are in contact at one end and separated by a thin copper wire at the other end.

The experimental arrangement in Figure 16 shows how interference fringes can be observed using a travelling microscope.

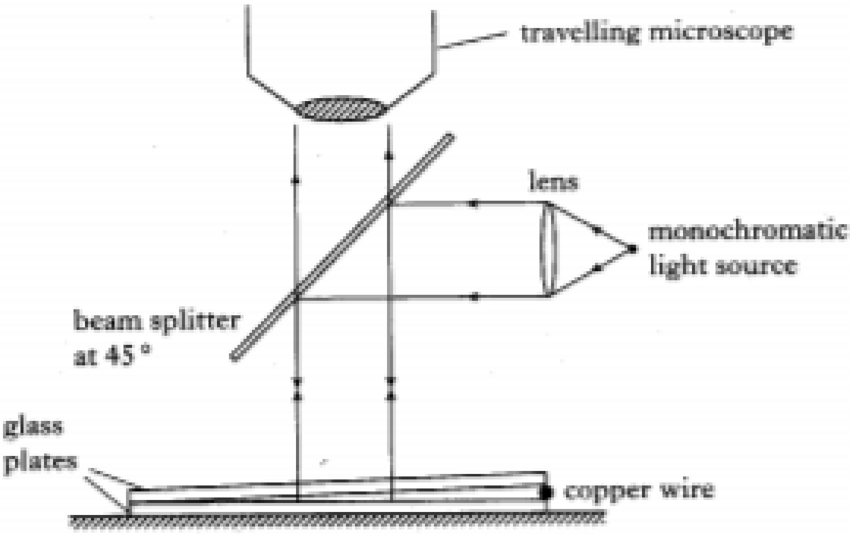


Figure 16

(*a*) In this arrangement, state whether the interference fringes are produced by division of amplitude or by division of wavefront. **1**

(*b*) Measurements are taken as follows:

separation of fringes	= 0·080 mm
length of each glass plate	= 75·0 mm
wavelength of monochromatic light	= 589 nm.

The separation of thin air wedge fringes is given by the expression

$$\Delta x = \frac{\lambda}{2\tan\theta}$$

where the symbols have their usual meanings.

Calculate the diameter of the copper wire. **2**

(*c*) Water enters the wedge and replaces all the air, as shown in Figure 17.

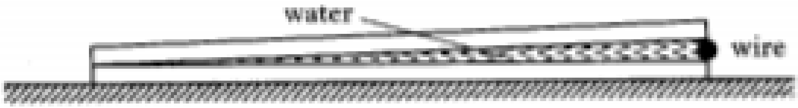


Figure 17

(i) Describe the change that occurs in the interference pattern.

(ii) Explain this change. **3**

(6)