

**1**

A student has a diffraction grating that is marked  $3.5 \times 10^3$  lines per m.

- (a) Calculate the percentage uncertainty in the number of lines per metre suggested by this marking.

percentage uncertainty = \_\_\_\_\_ %

**(1)**

- (b) Determine the grating spacing.

grating spacing = \_\_\_\_\_ mm

**(2)**

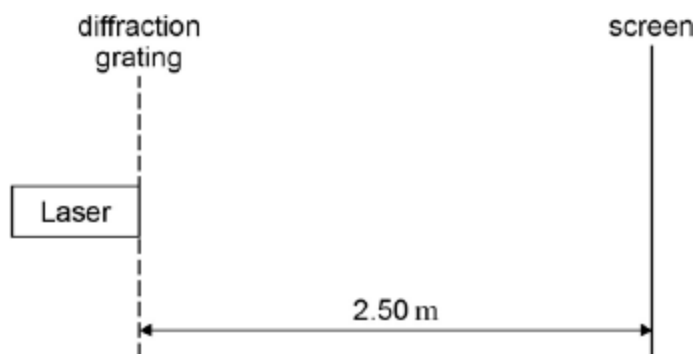
- (c) State the absolute uncertainty in the value of the spacing.

absolute uncertainty = \_\_\_\_\_ mm

**(1)**

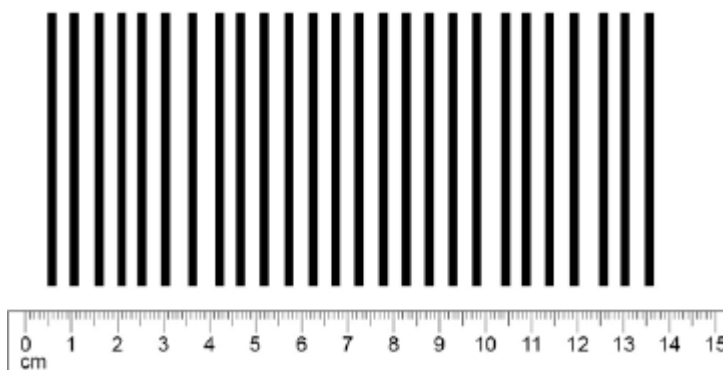
- (d) The student sets up the apparatus shown in **Figure 1** in an experiment to confirm the value marked on the diffraction grating.

**Figure 1**



The laser has a wavelength of 628 nm. **Figure 2** shows part of the interference pattern that appears on the screen. A ruler gives the scale.

**Figure 2**



Use **Figure 2** to determine the spacing between two adjacent maxima in the interference pattern. Show all your working clearly.

spacing = \_\_\_\_\_ mm

(1)

- (e) Calculate the number of lines per metre on the grating.

number of lines = \_\_\_\_\_

(2)

- (f) State and explain whether the value for the number of lines per m obtained in part (e) is in agreement with the value stated on the grating.

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(2)

- (g) State **one** safety precaution that you would take if you were to carry out the experiment that was performed by the student.

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(1)

(Total 10 marks)

- 2** Monochromatic light of wavelength 490 nm falls normally on a diffraction grating that has  $6 \times 10^5$  lines per metre. Which one of the following is correct?

A The first order is observed at angle of diffraction of  $17^\circ$ .

☐

B The second order is observed at angle of diffraction of  $34^\circ$ .

☐

C The third and higher orders are not produced.

☐

D A grating with more lines per metre could produce more orders.

☐

(Total 1 mark)

- 3** White light passes through a single narrow slit and illuminates a screen.

What is observed on the screen?

A a set of equally spaced white fringes

☐

B a central maximum made up of a spectrum surrounded by white fringes

☐

C a white central maximum surrounded by coloured fringes

☐

D a single narrow white line

☐

(Total 1 mark)

4

- (a) Explain what is meant by a progressive wave.

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(2)

- (b) **Figure 1** shows the variation with time of the displacement of one point in a progressive wave.

**Figure 1**

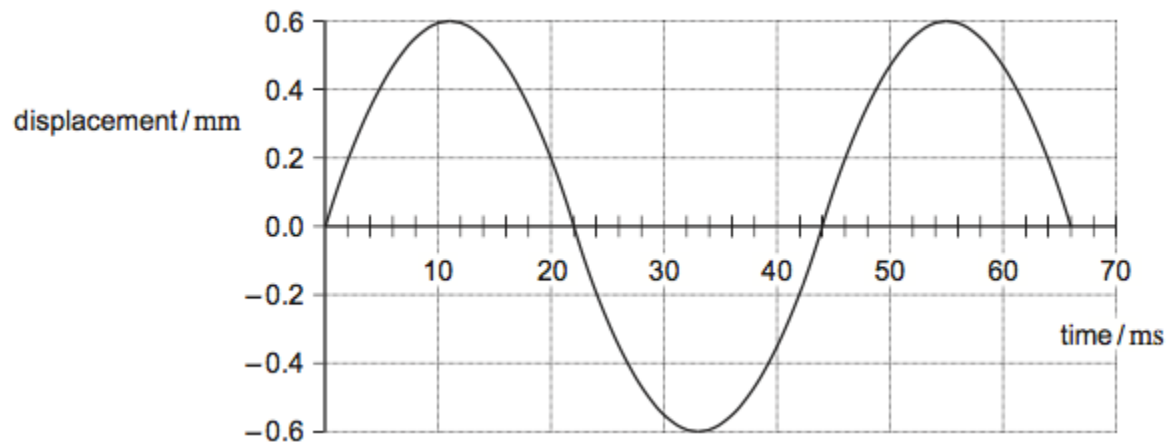
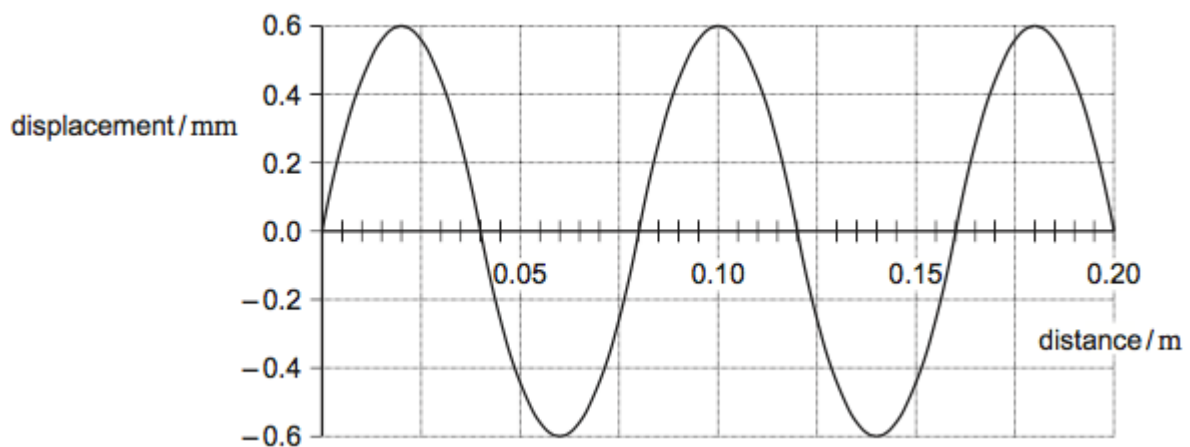


**Figure 2** shows the variation of displacement of the same wave with distance.

**Figure 2**



Use **Figures 1 and 2** to determine

- (i) the amplitude of the wave

amplitude = \_\_\_\_\_ mm

(1)

- (ii) the wavelength of the wave

wavelength = \_\_\_\_\_ m

(1)

- (iii) the frequency of the wave

frequency = \_\_\_\_\_ Hz

(1)

- (iv) the speed of the wave

speed = \_\_\_\_\_ m s<sup>-1</sup>

(1)

- (c) Which of the following statements apply?

Place a tick (✓) in the right-hand column for each correct statement.

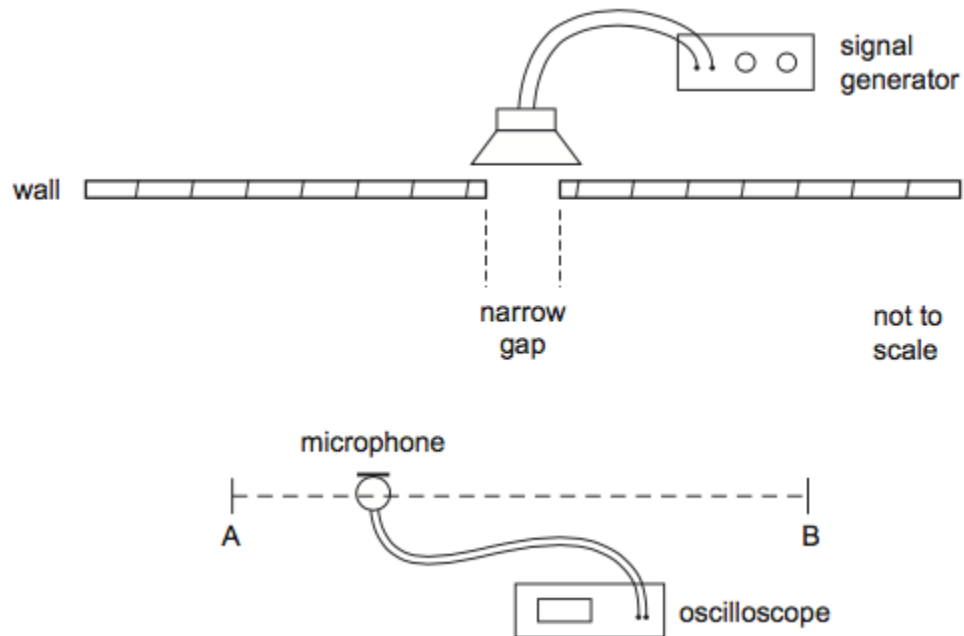
|                              | ✓ if correct |
|------------------------------|--------------|
| sound waves are transverse   |              |
| sound waves are longitudinal |              |
| sound waves can interfere    |              |
| sound waves can be polarised |              |

(1)

- (d) In an investigation, a single loudspeaker is positioned behind a wall with a narrow gap as shown in **Figure 3**.

A microphone attached to an oscilloscope enables changes in the amplitude of the sound to be determined for different positions of the microphone.

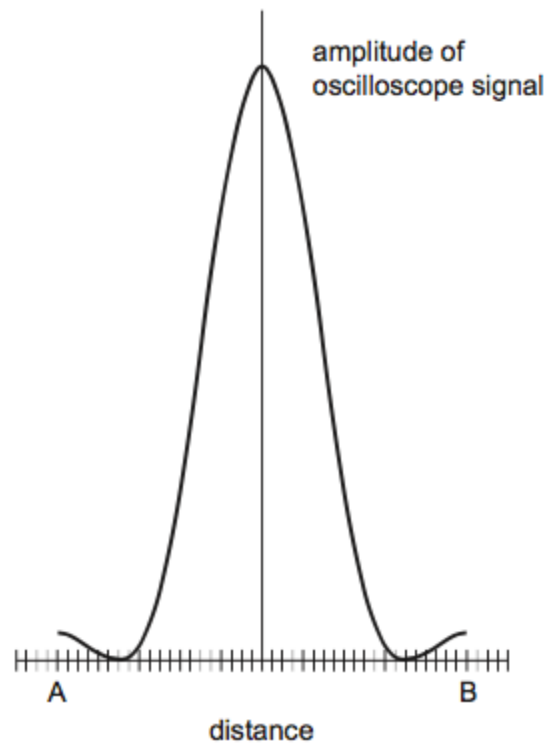
**Figure 3**



The amplitude of sound is recorded as the microphone position is moved along the line AB a large distance from the gap.

The result of the measurements is shown in **Figure 4**.

**Figure 4**



The signal generator is adjusted so that sound waves of the same amplitude but of a higher frequency are emitted by the loudspeaker. The investigation using the apparatus shown in **Figure 3** is then repeated.

Explain the effect this has on **Figure 4**.

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5

- (a) A laser emits *monochromatic light*.

Explain the meaning of the term monochromatic light.

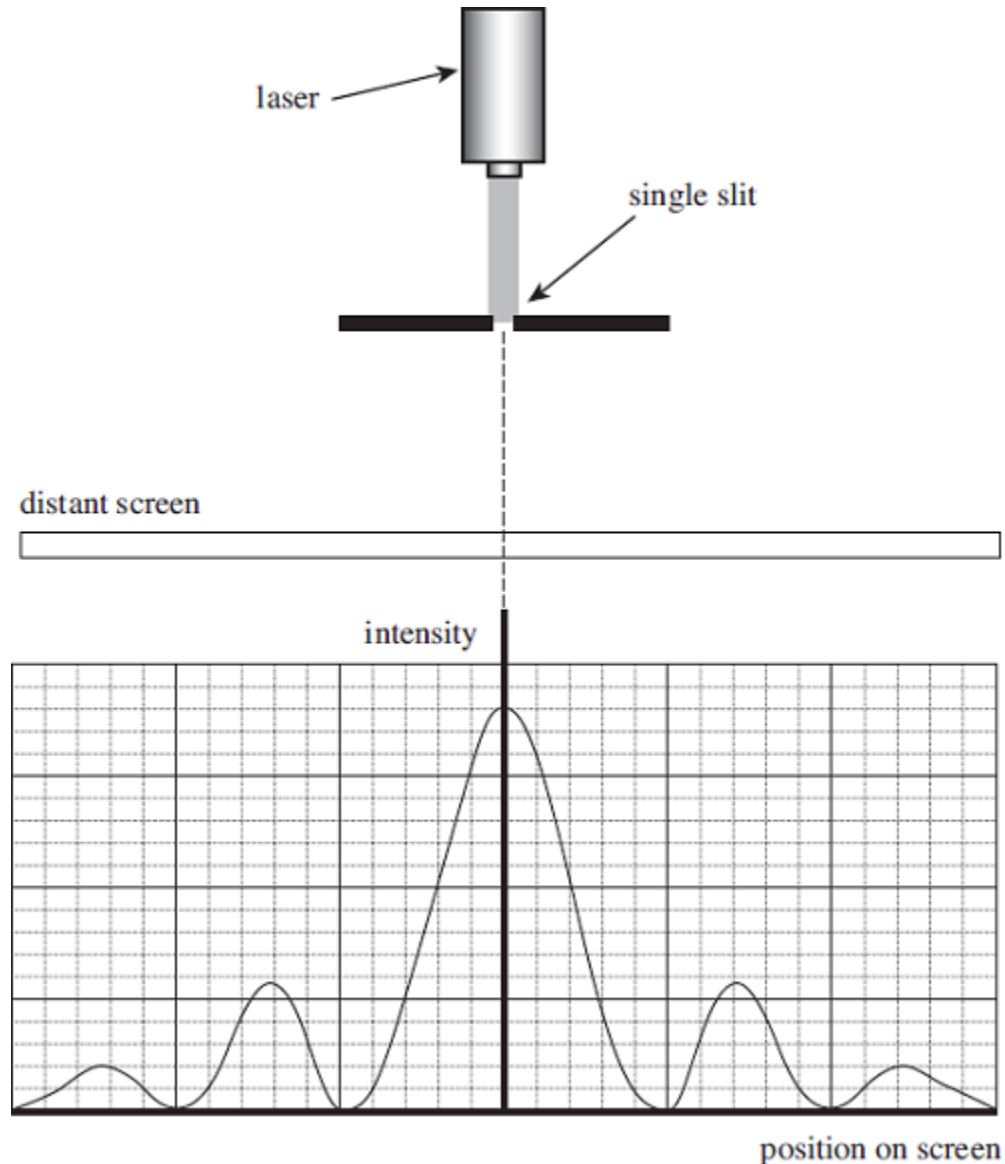
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(1)

- (b) The diagram below shows a laser emitting blue light directed at a single slit, where the slit width is greater than the wavelength of the light. The intensity graph for the diffracted blue light is shown.



The laser is replaced by a laser emitting red light.

On the axes shown in the diagram above sketch the intensity graph for a laser emitting red light.

(2)

- (c) State and explain **one** precaution that should be taken when using laser light

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(2)

- (d) The red laser light is replaced by a non-laser source emitting white light.

Describe how the appearance of the pattern would change.

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(3)

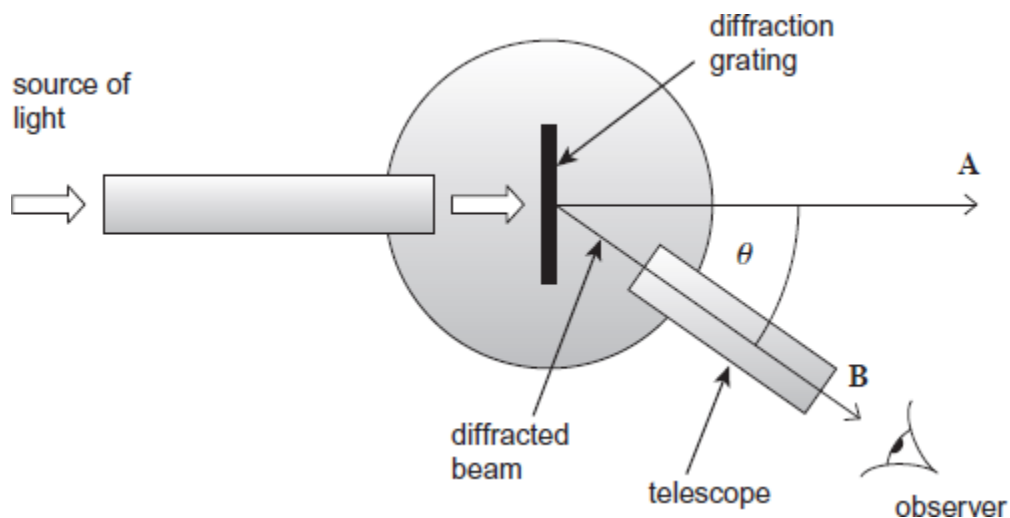
(Total 8 marks)

- 6** The figure below shows a spectrometer that uses a diffraction grating to split a beam of light into its constituent wavelengths and enables the angles of the diffracted beams to be measured.

- (a) Give **one** possible application of the spectrometer and diffraction grating used in this way.

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(1)

- (b) (i) When the spectrometer telescope is rotated from an initial angle of zero degrees, a spectrum is not observed until the angle of diffraction  $\theta$  is about  $50^\circ$ . State the order of this spectrum.

\_\_\_\_\_

(1)

- (ii) White light is directed into the spectrometer. Light emerges at **A** and **B**. State **one** difference between the light emerging at **B** compared to that emerging at **A**.

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(1)

- (c) The angle of diffraction  $\theta$  at the centre of the observed beam **B** in the image above is  $51.0^\circ$  and the grating has 1480 lines per mm.

Calculate the wavelength of the light observed at the centre of beam **B**.

wavelength \_\_\_\_\_ m

(3)

- (d) Determine by calculation whether any more orders could be observed at the wavelength calculated in part (c).

(2)

(Total 8 marks)

7

A diffraction grating has 300 lines per mm. It is illuminated with monochromatic light of wavelength 540 nm.

Calculate the angle of the 2<sup>nd</sup> order maximum, giving your answer to the appropriate number of significant figures.

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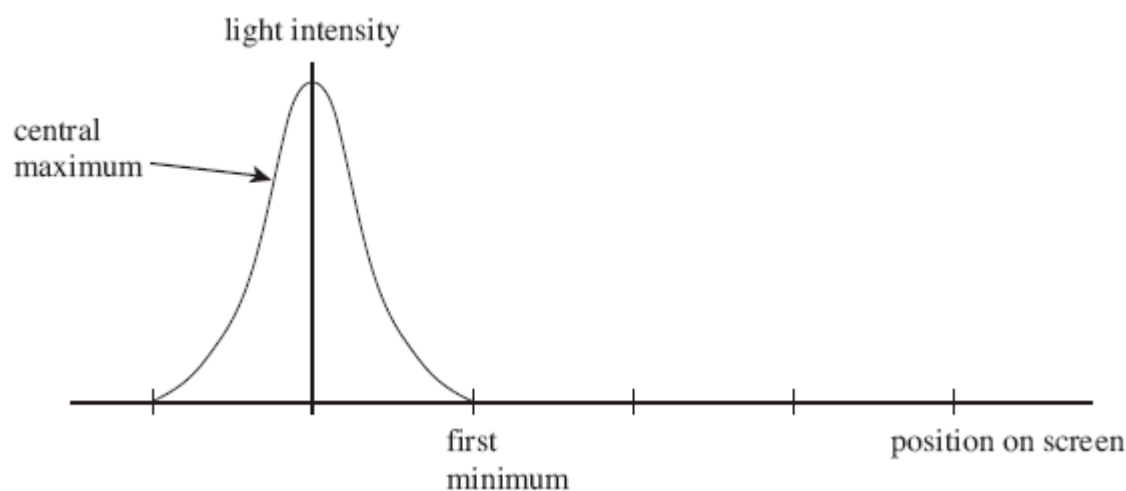
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angle \_\_\_\_\_ degrees

(Total 4 marks)

8

A single slit diffraction pattern is produced on a screen using a laser. The intensity of the central maximum is plotted on the axes in the figure below.



- (a) On the figure above, sketch how the intensity varies across the screen to the right of the central maximum.

(2)

- (b) A laser is a source of *monochromatic*, *coherent* light. State what is meant by

monochromatic light \_\_\_\_\_

\_\_\_\_\_

coherent light \_\_\_\_\_

\_\_\_\_\_

(2)

- (c) Describe how the pattern would change if light of a longer wavelength was used.

\_\_\_\_\_

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- (d) State **two** ways in which the appearance of the fringes would change if the slit was made narrower.

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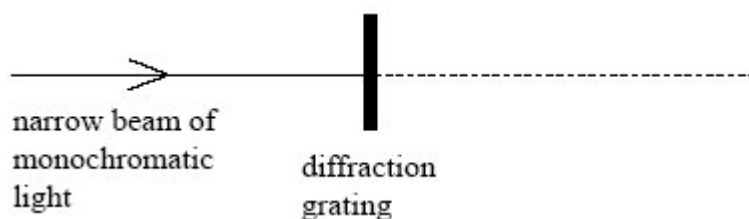
(2)

- (e) The laser is replaced with a lamp that produces a narrow beam of white light. Sketch and label the appearance of the fringes as you would see them on a screen.

(3)

(Total 10 marks)

- 9** A narrow beam of monochromatic light of wavelength 590 nm is directed normally at a diffraction grating, as shown in the diagram below.



- (a) The grating spacing of the diffraction grating is  $1.67 \times 10^{-6}$  m.
- (i) Calculate the angle of diffraction of the second order diffracted beam.

answer \_\_\_\_\_ degrees

(4)

- (ii) Show that no beams higher than the second order can be observed at this wavelength.

(3)

- (b) The light source is replaced by a monochromatic light source of unknown wavelength. A narrow beam of light from this light source is directed normally at the grating. Measurement of the angle of diffraction of the second order beam gives a value of  $42.1^\circ$ .

Calculate the wavelength of this light source.

answer \_\_\_\_\_ m

(2)

(Total 9 marks)

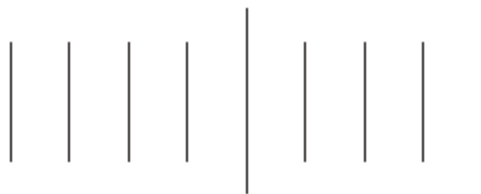
10

Light of wavelength  $\lambda$  is incident normally on a diffraction grating for which adjacent lines are a distance  $3\lambda$  apart. What is the angle between the second order maximum and the straight-through position?

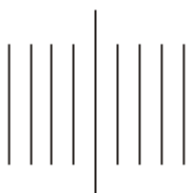
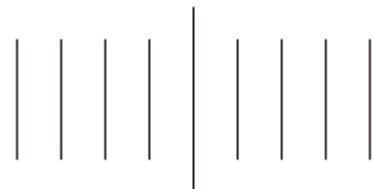
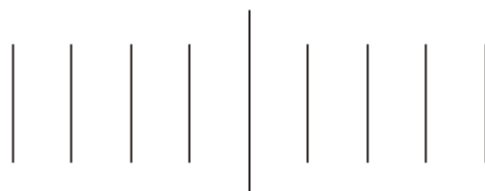
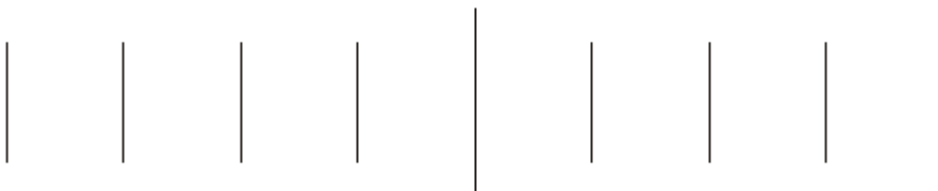
- A  $9.6^\circ$
- B  $20^\circ$
- C  $42^\circ$
- D There is no second order maximum.

(Total 1 mark)

11



The diagram above shows the first four diffraction orders each side of the zero order when a beam of monochromatic light is incident normally on a diffraction grating of slit separation  $d$ . All the angles of diffraction are small. Which one of the patterns, **A** to **D**, drawn on the same scale, is obtained when the grating is exchanged for one with a slit separation  $\frac{d}{2}$ ?

**A****B****C****D****(Total 1 mark)**

12

(a) State what is meant by *coherent sources* of light.

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**(2)**

(b)

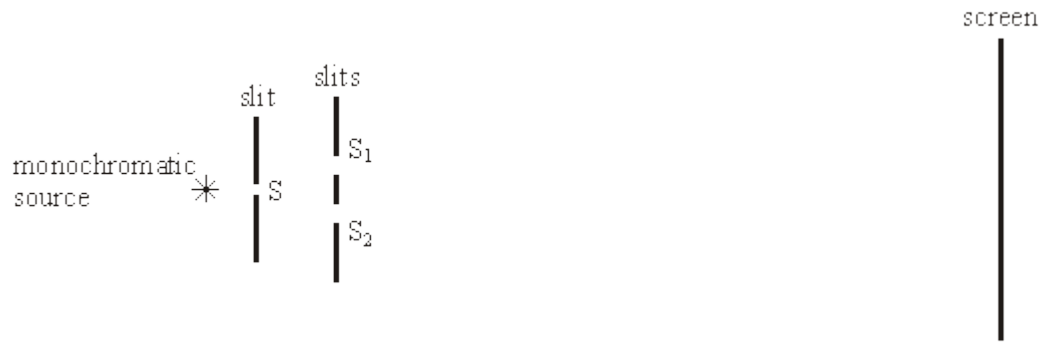


**Figure 1**

Young's fringes are produced on the screen from the monochromatic source by the arrangement shown in **Figure 1**.

You may be awarded marks for the quality of written communication in your answers.

(i) Explain why slit S should be narrow.

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(ii) Why do slits S<sub>1</sub> and S<sub>2</sub> act as coherent sources?

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**(4)**

- (c) The pattern on the screen may be represented as a graph of intensity against position on the screen. The central fringe is shown on the graph in **Figure 2**. Complete this graph to represent the rest of the pattern by drawing on **Figure 2**.

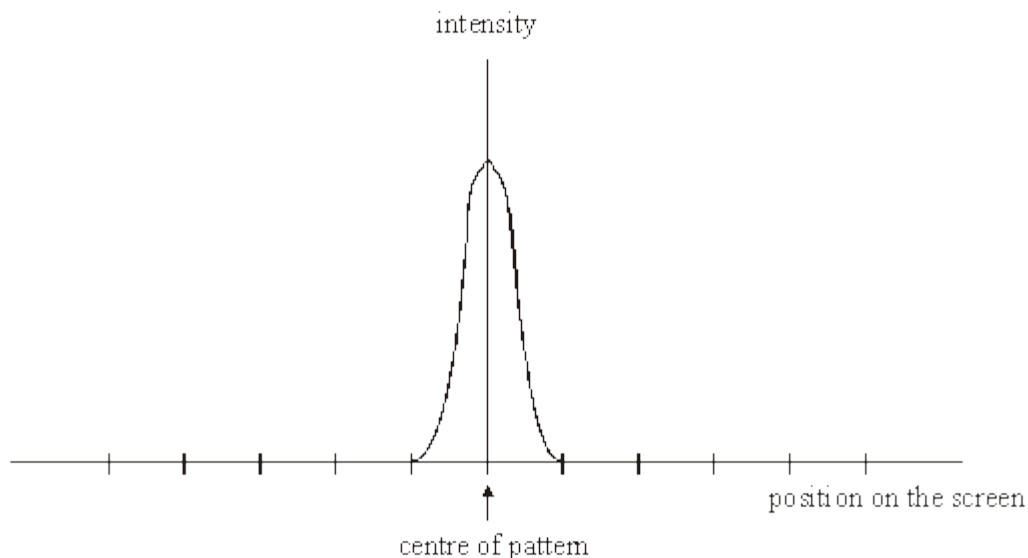


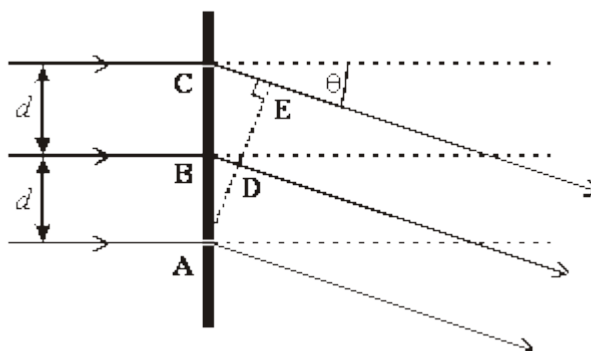
**Figure 2**

(2)

(Total 8 marks)

**13**

The diagram below shows a section of a diffraction grating. Monochromatic light of wavelength  $\lambda$  is incident normally on its surface. Light waves diffracted through angle  $\theta$  form the **second** order image after passing through a converging lens (not shown). **A**, **B** and **C** are adjacent slits on the grating.



- (a) (i) State the phase difference between the waves at **A** and **D**.

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- (ii) State the path length between **C** and **E** in terms of  $\lambda$ .

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- (iii) Use your results to show that, for the second order image,  
 $2\lambda = d \sin \theta$ , where  $d$  is the distance between adjacent slits.

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(3)

- (b) A diffraction grating has  $4.5 \times 10^5$  lines  $\text{m}^{-1}$ . It is being used to investigate the line spectrum of hydrogen, which contains a visible blue-green line of wavelength 486 nm. Determine the highest order diffracted image that could be produced for this spectral line by this grating.

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(2)

(Total 5 marks)

14

Light of wavelength  $\lambda$  is incident normally on a diffraction grating of slit separation  $4\lambda$ . What is the angle between the second order maximum and third order maximum?

- A 14.5°
- B 18.6°
- C 48.6°
- D 71.4°

(Total 1 mark)

**15**

A narrow beam of monochromatic light falls on a diffraction grating at normal incidence. The second order diffracted beam makes an angle of  $45^\circ$  with the grating. What is the highest order visible with this grating at this wavelength?

- A 2
- B 3
- C 4
- D 5

(Total 1 mark)

**16**

Monochromatic light of wavelength 590 nm is incident normally on a plane diffraction grating having  $4 \times 10^5$  lines  $\text{m}^{-1}$ . An interference pattern is produced. What is the highest order visible in this interference pattern?

- A 2
- B 3
- C 4
- D 5

(Total 1 mark)

**17**

Using a diffraction grating with monochromatic light of wavelength 500 nm incident normally, a student found the 2nd order diffracted maxima in a direction at  $30^\circ$  to the central bright fringe. What is the number of lines per metre on the grating?

- A  $2 \times 10^4$
- B  $2 \times 10^5$
- C  $4 \times 10^5$
- D  $5 \times 10^5$

(Total 1 mark)

- (a) A double slit interference experiment is set up in a laboratory using a source of yellow monochromatic light of wavelength  $5.86 \times 10^{-7}$  m. The separation of the two **vertical** parallel slits is 0.36 mm and the distance from the slits to the plane where the fringes are observed is 1.80 m.

- (i) Describe the appearance of the fringes.

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- (ii) Calculate the fringe separation, and also the angle between the middle of the central fringe and the middle of the second bright fringe.

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- (iii) Explain why more fringes will be seen if each of the slits is made narrower, assuming that no other changes are made.

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(8)

- (b) Light of wavelength  $5.86 \times 10^{-7}$  m falls at right angles on a diffraction grating which has 400 lines per mm.

- (i) Calculate the angle between the straight through image and the first order image.

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- (ii) Determine the highest order image which can be seen with this arrangement.

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(5)

- (c) Give **two** reasons why the diffraction grating arrangement is more suitable for the accurate measurement of the wavelength of light than the two-slit interference arrangement.

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(2)

(Total 15 marks)

19

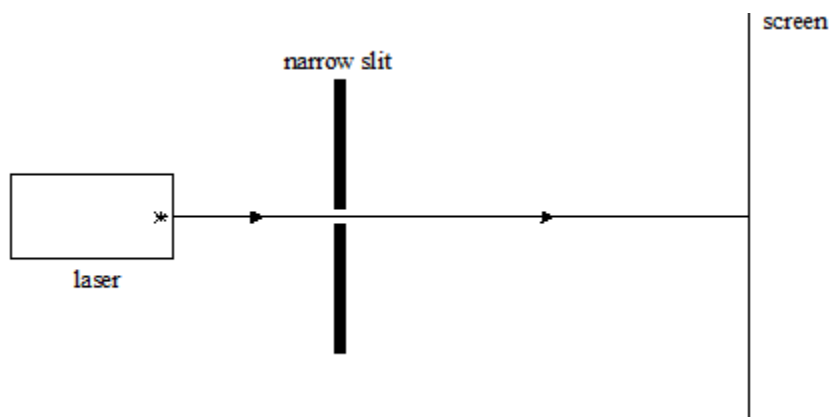


Figure 1

Red light from a laser is passed through a single narrow slit, as shown in **Figure 1**. A pattern of bright and dark regions can be observed on the screen which is placed several metres beyond the slit.

- (a) The pattern on the screen may be represented as a graph of intensity against distance along the screen. The graph has been started in outline in **Figure 2**. The central bright region is already shown. Complete this graph to represent the rest of the pattern by drawing on **Figure 2**.

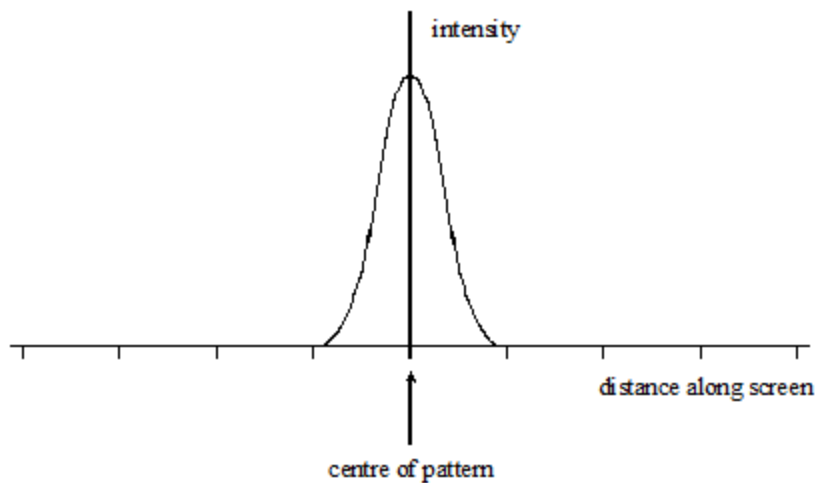


Figure 2

(4)

(b) State the effect on the pattern if each of the following changes is made separately.

(i) The width of the narrow slit is reduced.

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(ii) With the original slit width, the intense red source is replaced with an intense source of green light.

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(3)

(Total 7 marks)

20

(a) A helium-neon laser produces monochromatic light of wavelength 632.8 nm which falls normally on a diffraction grating. A first order maximum is produced at an angle of  $18.5^\circ$  measured from the normal to the grating.

Calculate

(i) the number of lines per metre on the grating,

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- (ii) the highest order which is observable.

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(6)

- (b) When the grating is used with a different monochromatic source, the first order maximum is observed at an angle of  $17.2^\circ$ .

Calculate the wavelength of this second source.

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(2)

(Total 8 marks)

21

- (a)

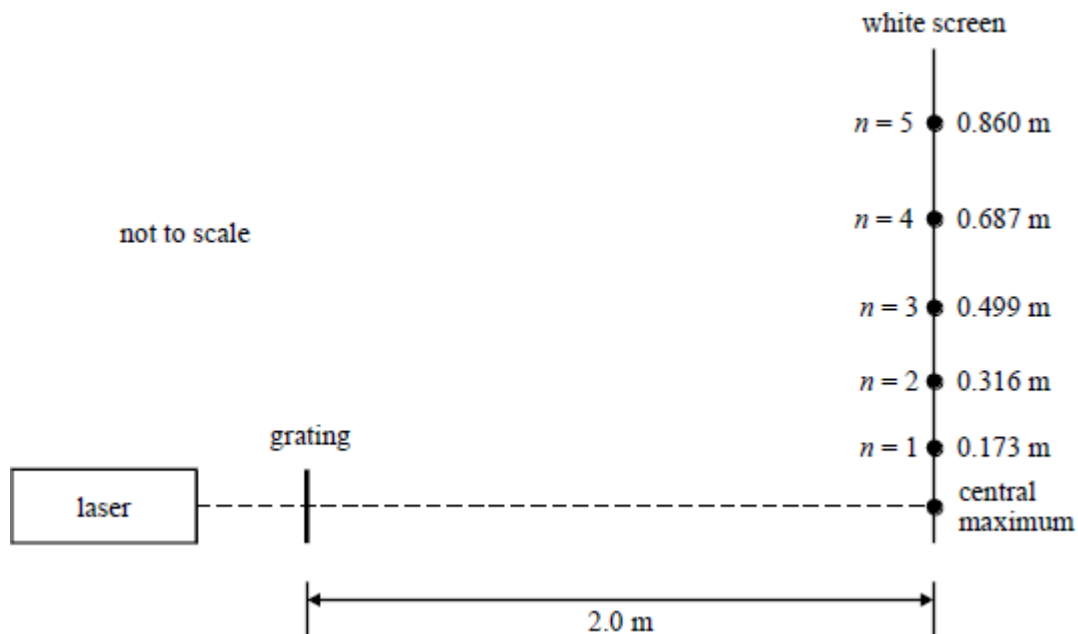


Figure 1

In a laboratory experiment, monochromatic light of wavelength 633 nm from a laser is incident normal to a diffraction grating. The diffracted waves are received on a white screen which is parallel to the plane of the grating and 2.0 m from it. **Figure 1** shows the positions of the diffraction maxima with distances measured from the central maximum.

By means of a graphical method, use all these measurements to determine a mean value for the number of rulings per unit length of the grating.

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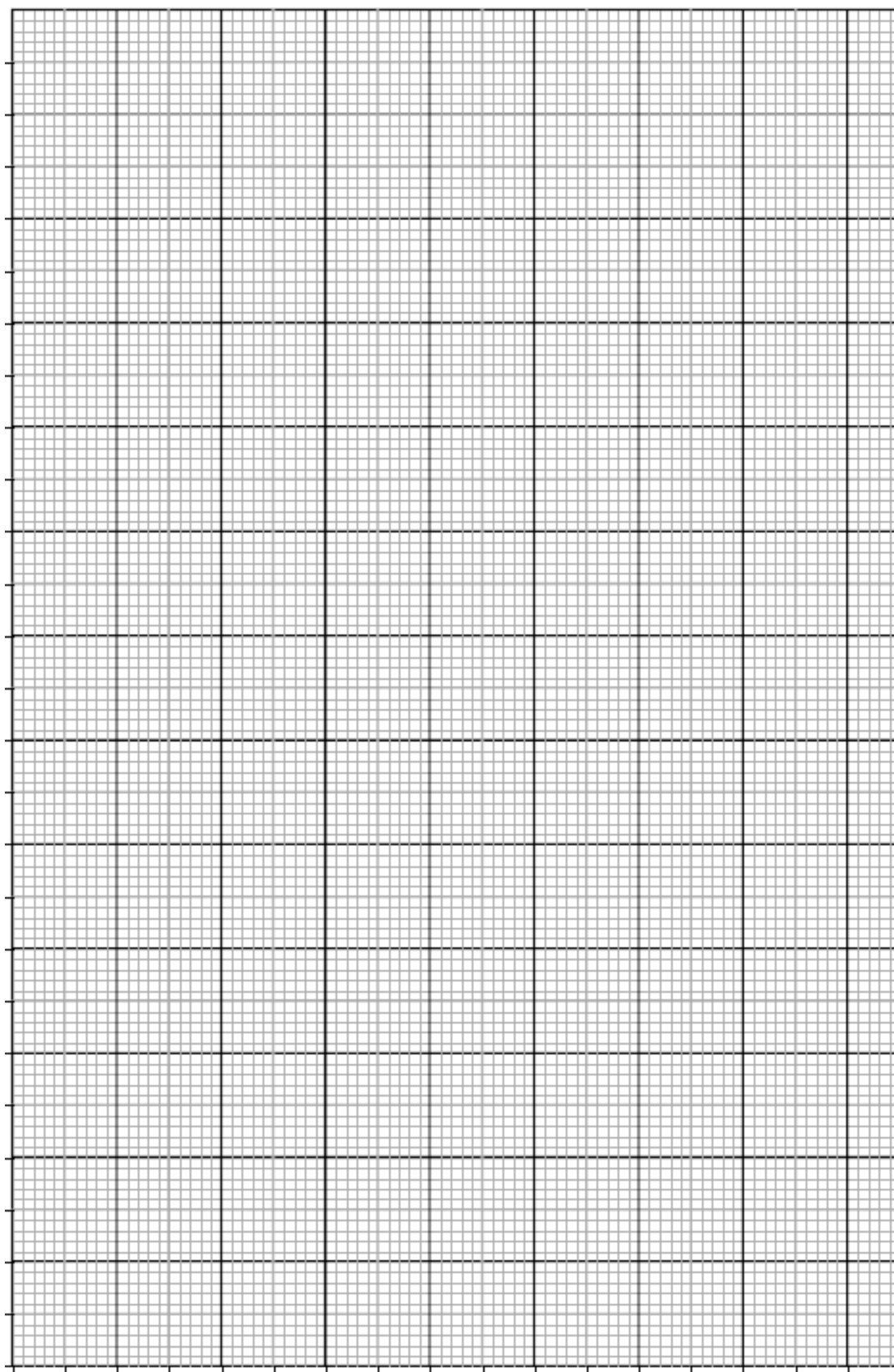
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(b) Describe and explain the effect, if any, on the appearance of the diffraction pattern of

(i) using a grating which has more rulings per unit length.

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(ii) using a laser source which has a shorter wavelength.

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(iii) increasing the distance between the grating and the screen.

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**(6)**

- (c) **Figure 2**, below, shows the diffracted waves from four narrow slits of a diffraction grating similar to the one described in part (a). The slit separation  $AB = BC = CD = DE = d$  and EQ is a line drawn at a tangent to several wavefronts and which makes an angle  $\theta$  with the grating.

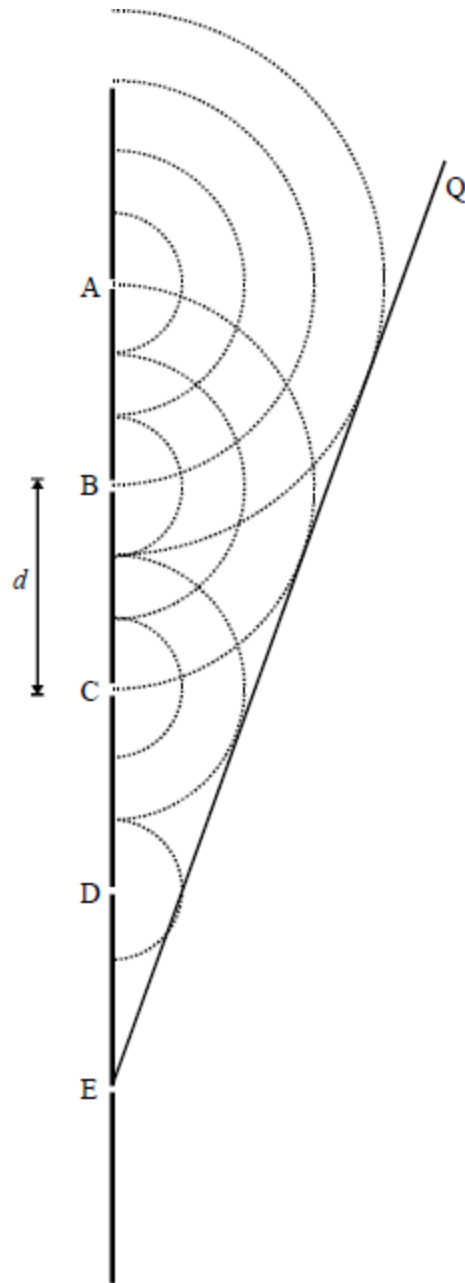


**Figure 2**

- (i) Explain why the waves advancing perpendicular to EQ will reinforce if superposed.

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(ii) Show that this will happen when  $\sin \theta = \frac{\lambda}{d}$ .

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(3)

(Total 15 marks)

22

Red light of wavelength  $7.00 \times 10^{-7}$  m, incident normally on a diffraction grating, gave a first order maximum at an angle of  $75^\circ$ .

(a) Calculate the spacing of the diffraction grating.

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(1)

(b) Calculate the angle at which the first order maximum for violet light of wavelength  $4.50 \times 10^{-7}$  m would be observed.

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(1)

(c) At what angle or angles would a detector receive radiation which is of wavelength  $7.50 \times 10^{-7}$  m transmitted by the grating? Explain your answer.

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(2)

(Total 4 marks)

**23**

- (a) A student stands some distance away from a wall and claps her hands. She listens to the echoes produced by the sound reflected from the wall and adjusts her rate of clapping so that each clap coincides with the echo of the previous clap. A fellow student counts the number of times she claps in 20 s.
- (i) There were 47 claps in 20 s.  
Calculate the time between two successive claps.

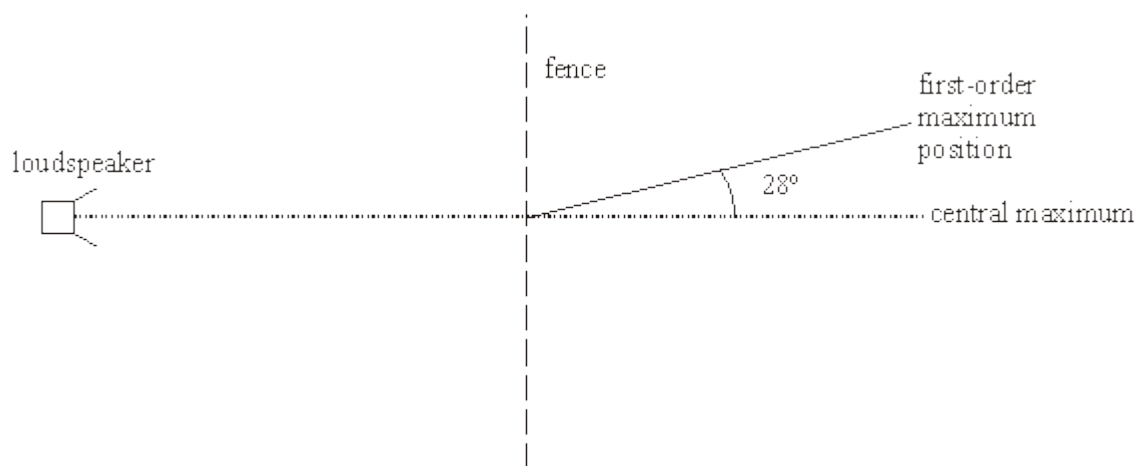
time between two successive claps \_\_\_\_\_

- (ii) The speed of sound in the air is  $340 \text{ m s}^{-1}$ . Calculate the distance of the student from the wall.

distance from wall \_\_\_\_\_

**(3)**

- (b) The student goes on to carry out a diffraction experiment. She stands on one side of a fence that consists of evenly-spaced wooden strips. The fence behaves as a diffraction grating for sound waves. The figure below shows the arrangement.



- (i) She uses a loudspeaker to send a sound wave of frequency 2.4 kHz towards the fence.

Calculate the wavelength of this sound wave.

speed of sound in air,  $v = 340 \text{ m s}^{-1}$

wavelength \_\_\_\_\_

- (ii) A diffracted first-order maximum is observed at an angle of  $28^\circ$ . Calculate the spacing between adjacent wooden strips.

strip spacing \_\_\_\_\_

- (iii) Determine the highest order of maximum that could be heard.

highest order \_\_\_\_\_

**(6)**

**(Total 9 marks)**

A scanning photometer is a device in which the voltage across an LDR (light dependent resistor) varies with the light intensity incident on the LDR.

**Figure 1** shows a laser beam of wavelength 633 nm incident normally on a diffraction grating. The LDR of a scanning photometer is moved across the diffracted beam and produces the scan shown in **Figure 2**. This shows the central bright fringe with one further maximum (the first order image) on each side of it. The distance from the diffraction grating to the LDR is 265 mm.

**Figure 1**

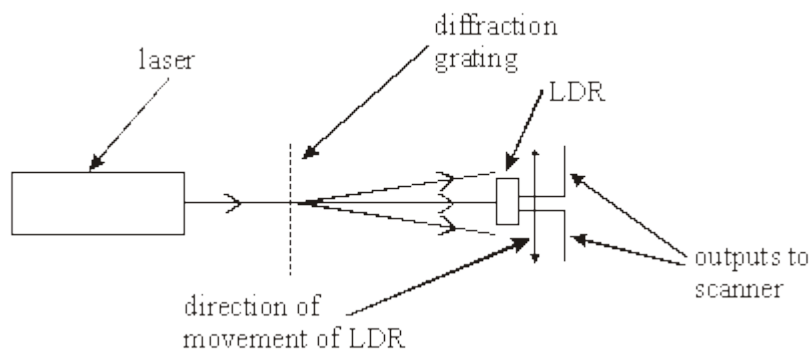
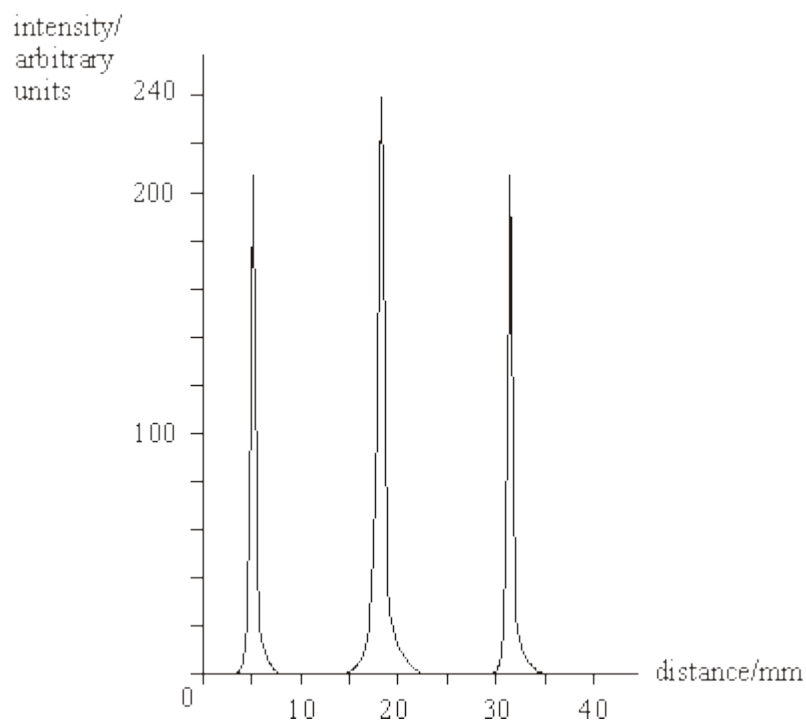


**Figure 2**



- (i) Show that the angle of the first order image measured from the straight through position is approximately  $3^\circ$ .
- (ii) Calculate the number of lines per mm on the diffraction grating.

**(Total 6 marks)**

**25**

A diffraction grating has 940 lines per mm.

- (a) Calculate the distance between adjacent lines on the grating.

distance between lines \_\_\_\_\_

**(1)**

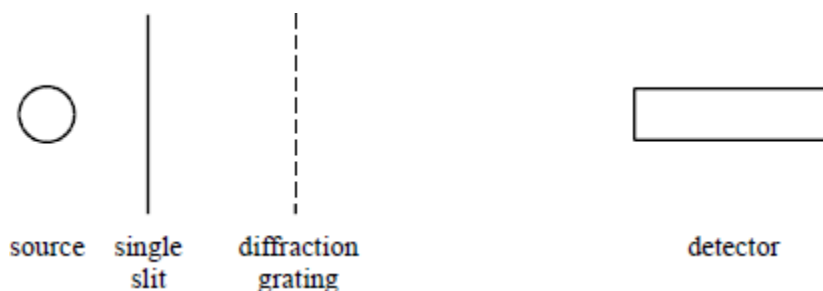
- (b) Monochromatic light is incident on the grating and a second-order spectral line is formed at an angle of  $55^\circ$  from the normal to the grating. Calculate the wavelength of the light.

wavelength \_\_\_\_\_

**(3)**

**(Total 4 marks)**

The diagram below is an arrangement for analysing the light emitted by a source.



- (a) Suggest a light source that would emit a continuous spectrum.

\_\_\_\_\_

(1)

- (b) The light source emits a range of wavelengths from 500 nm to 700 nm. The light is incident on a diffraction grating that has 10 000 lines per metre.

- (i) Calculate the angle from the straight through direction at which the first order maximum for the 500 nm wavelength is formed.

Angle = \_\_\_\_\_

(3)

- (ii) Calculate the angular width of the first order spectrum.

Angular width \_\_\_\_\_

(1)

- (iii) The detector is positioned 2.0 m from the grating. Calculate the distance between the extreme ends of the first order spectrum in this position.

Distance = \_\_\_\_\_

(1)

- (c) The single slit is initially illuminated by light from a point source that is 0.02 m from the slit.

State and explain how the intensity of light incident on the single slit changes when the light source is moved to a position 0.05 m from the slit.

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

(4)

(Total 10 marks)

|     |                                                                                                                                                                                                                   |                                                                                           |          |   |
|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|----------|---|
| 1   | (a)                                                                                                                                                                                                               | 2.9% ✓                                                                                    |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | Allow 3% |   |
|     |                                                                                                                                                                                                                   |                                                                                           |          | 1 |
|     | (b)                                                                                                                                                                                                               | $\frac{1}{3.5 \times 10^3}$ seen ✓                                                        |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           |          | 1 |
|     |                                                                                                                                                                                                                   | 0.29 mm or $2.9 \times 10^{-4}$ m ✓ must see 2 sf <b>only</b>                             |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           |          | 1 |
|     | (c)                                                                                                                                                                                                               | $\pm 0.01$ mm ✓                                                                           |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           |          | 1 |
|     | (d)                                                                                                                                                                                                               | Clear indication that at least 10 spaces have been measured to give a spacing = 5.24 mm ✓ |          |   |
|     |                                                                                                                                                                                                                   | spacing from at least 10 spaces<br>Allow answer within range $\pm 0.05$                   |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | 1        |   |
| (e) | Substitution in $d \sin \theta = n\lambda$ ✓                                                                                                                                                                      |                                                                                           |          |   |
|     |                                                                                                                                                                                                                   | The 25 spaces could appear here as $n$ with $\sin \theta$ as $0.135 / 2.5$                |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | 1        |   |
|     |                                                                                                                                                                                                                   | $d = 0.300 \times 10^{-3}$ m so<br>number of lines = $3.34 \times 10^3$ ✓                 |          |   |
|     |                                                                                                                                                                                                                   | Condone error in powers of 10 in substitution<br>Allow ecf from 1-4 value of spacing      |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | 1        |   |
| (f) | Calculates % difference (4.6%) ✓                                                                                                                                                                                  |                                                                                           |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | 1        |   |
|     |                                                                                                                                                                                                                   | <b>and</b> makes judgement concerning agreement ✓<br>Allow ecf from 1-5 value             |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | 1        |   |
| (g) | care not to look directly into the laser beam ✓<br><b>OR</b><br>care to avoid possibility of reflected laser beam ✓<br><b>OR</b><br>warning signs that laser is in use outside the laboratory ✓<br><b>ANY ONE</b> |                                                                                           |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | 1        |   |
|     |                                                                                                                                                                                                                   |                                                                                           | [10]     |   |
| 2   | A                                                                                                                                                                                                                 |                                                                                           |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | [1]      |   |
| 3   | C                                                                                                                                                                                                                 |                                                                                           |          |   |
|     |                                                                                                                                                                                                                   |                                                                                           | [1]      |   |

**[10]**

[1]

[1]

4

- (a) A wave transfers energy from one point to another ✓  
without transferring material / (causing permanent displacement of the medium) ✓ owtte

2

- (b) (i) 0.6 (mm) or 0.60 (mm) ✓

1

- (ii) 0.080 (m) ✓

*Allow 1 sig fig*

1

- (iii)  $f = 1/T = 1/0.044 = 23$  (Hz) ✓ (22.7 Hz)

1

- (iv)  $v = f \lambda = 22.7 \times 0.080 = 1.8$  (m s<sup>-1</sup>) ✓ (1.82 m s<sup>-1</sup>)

*allow CE  $v = (biii) \times (bii)$  but working must be shown*

*1 sig fig not acceptable*

1

- (c)

|                            |                              |                           |                              |
|----------------------------|------------------------------|---------------------------|------------------------------|
| sound waves are transverse | sound waves are longitudinal | sound waves can interfere | sound waves can be polarised |
|                            | ✓                            | ✓                         |                              |

1

- (d) the wavelength would be smaller  
smaller spread in main peak or more peaks (between A and B)  
the central peak is higher (owtte)  
as the energy is concentrated over a smaller area (owtte)  
reference to ( $\sin \theta_{\min} = \lambda/d$ )  
✓ ✓ ✓ any 3 lines max 3

*Note that the marks here are for use of knowledge rather than performing calculations.*

*No bod if writing does not make increase or decrease clearly distinct.*

*Marking should be lenient.*

3

[10]

5

- (a) single frequency (or wavelength or photon energy) ✓  
*not single colour*  
*accept 'very narrow band of frequencies'*

1

- (b) subsidiary maxima (centre of) peaks further away from centre ✓

*For second mark: One square tolerance horizontally. One whole subsid max seen on either side.*

subsidiary maxima peaks further away from centre **AND** central maximum twice width of subsidiaries **AND** symmetrical ✓

*Central higher than subsid and subsid same height  $\pm 2$  squares.*

*Minima on the x axis  $\pm 1$  square.*

*Must see 1 whole subsidiary for second mark*

2

- (c) ONE FROM:

- don't shine towards a person
- avoid (accidental) reflections
- wear laser safety goggles
- 'laser on' warning light outside room
- Stand behind laser
- other sensible suggestion ✓

*allow green goggles for red laser, 'high intensity goggles', etc.*

*not 'goggles', 'sunglasses'*

eye / skin damage could occur ✓

2

- (d) 3 from 4 ✓✓✓

- central white (fringe)
- each / every / all subsidiary maxima are composed of a spectrum (clearly stated or implied)
- each / every / all subsidiary maxima are composed of a spectrum (clearly stated or implied) **AND** (subsidiary maxima) have violet (allow blue) nearest central maximum **OR** red furthest from centre
- Fringe spacing less / maxima are wider / dark fringes are smaller (or not present)

*allow 'white in middle'*

*For second mark do not allow 'there are colours' or 'there is a spectrum' on their own*

*Allow 'rainbow pattern' instead of spectrum but not 'a rainbow'*

*Allow 'rainbow pattern' instead of spectrum but not 'a rainbow'*

*If they get the first, the second and third are easier to award*

*Allow full credit for annotated sketch*

3

[8]

6

- (a) one of:  
 (spectral) analysis of light from stars  
 (analyse) composition of stars  
 chemical analysis  
 measuring red shift \ rotation of stars ✓

insufficient answers:

'observe spectra', 'spectroscopy', 'view absorption \ emission spectrum', 'compare spectra', 'look at light from stars'.

*Allow : measuring wavelength or frequency from a named source of light*

*Allow any other legitimate application that specifies the source of light. E.g.*

*absorbtion \ emission spectra in stars,  
 'observe spectra of materials'*

1

- (b) (i) first order beam  
 first order spectrum  
 first order image  
 ✓

*Allow 'n = 1', '1', 'one', 1<sup>st</sup>*

1

- (ii) the light at A will appear white (and at B there will be a spectrum)  
 OR greater intensity at A ✓

1

- (c) ( $d = 1 / (\text{lines per mm} \times 10^3)$ )  
 $= 6.757 \times 10^{-7} \text{ (m)}$  OR  $6.757 \times 10^{-4} \text{ (mm)}$  ✓

$$(n\lambda = d \sin \theta)$$

$$= 6.757 \times 10^{-7} \times \sin 51.0 \text{ ✓ ecf **only** for :}$$

- incorrect power of ten in otherwise correct calculation of d
- use of d = 1480, 1.48, 14.8 (etc)
- from incorrect order in bii

$$= 5.25 \times 10^{-7} \text{ (m)} \text{ ✓ ecf **only** for :}$$

- incorrect power of ten in otherwise correct d
- from incorrect order in bii

*Some working required for full marks. Correct answer only gets 2*

*Power of 10 error in d gets max 2*

*For use of d in mm, answer =*

$$5.25 \times 10^{-4} \text{ gets max 2}$$

*n = 2 gets max 2 unless ecf from bii*

*use of d = 1480 yields wavelength of 1150m*

3

(d)  $n = d (\sin 90) / \lambda$  OR  $n = 6.757 \times 10^{-7} / 5.25 \times 10^{-7}$  ✓ ecf both numbers from c  
 $= 1.29$  so no more beams observed ✓ or answer consistent with their working

**OR**

$2 = d (\sin \theta) / \lambda$  OR  $\sin \theta = 2 \times 5.25 \times 10^{-7} / 6.757 \times 10^{-7}$  ✓ ecf both numbers from c

$\sin \theta = 1.55$  (so not possible to calculate angle) so no more beams ✓

**OR**  $\sin^{-1}(2 \times (\text{their } \lambda / \text{their } d))$  ✓

(not possible to calculate) so no more beams ✓ ecf

*Accept 1.28, 1.3*

*Second line gets both marks*

*Conclusion consistent with working*

2

[8]

7

$\sin \theta = n\lambda/d$  in this form/correct calculations of  $d/\lambda = 1/300$

C1

substitutes correctly – condone powers of 10

C1

18.9

C1

2 or 3 sf only

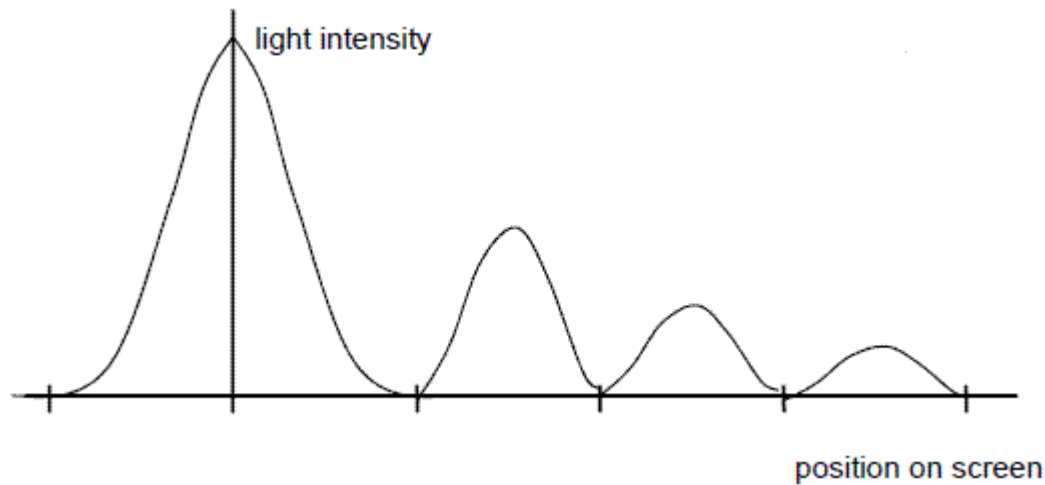
A1

[4]

8

- (a) 3 subsidiary maxima in correct positions (1)

intensity decreasing (1)



2

- (b) a single wavelength (1)

constant phase relationship/difference (1)

2

- (c) maxima further apart/central maximum wider/subsidiary maximum wider/maxima are wider (1)

1

- (d) wider/increased separation (1)

lower intensity (1)

2

- (e) distinct fringes shown with subsidiary maxima (1)

indication that colours are present within each subsidiary maxima (1)

blue/violet on the inner edge or red outer for at least one subsidiary maximum (1)

(middle of) central maximum white (1)

3

[10]

9

- (a) (i)  $= 590 \times 10^{-9} \text{m}$  (1)

(using  $d \sin \theta = n\lambda$  gives)

$$\sin \theta = \frac{n\lambda}{d} \text{ or } = \frac{2 \times 590 \times (10^{-9})}{1.67 \times 10^{-6}} \text{ (1) } = 0.707 \text{ or}$$

$$7.07 \times 10^8 \text{ if nm used (1)}$$

$$\theta = 45.0^\circ \text{ (1) (accept } 45^\circ)$$

(ii)  $(\sin \theta \leq 1)$  gives  $\frac{n\lambda}{d} \leq 1$  or  $n \leq \frac{d}{\lambda}$  or  $= \frac{1.67 \times 10^{-6}}{590 \times 10^{-9}}$  **(1)** = 2.83 **(1)**

so 3<sup>rd</sup> order or higher order is not possible **(1)**

alternative solution:

(substituting)  **$n = 3$**  (into  $d \sin \theta = n\lambda$  gives) **(1)**

$$\sin \theta (= \frac{n\lambda}{d} = \frac{3 \times 590 \times 10^{-9}}{1.67 \times 10^{-6}}) = 1.06 \text{ **(1)**}$$

gives 'error'/which is not possible **(1)**

7

(b) (using  $d \sin \theta = n\lambda$  gives)

$$2\lambda = 1.67 \times 10^{-6} \times \sin 42.1 \text{ **(1)**}$$

$$\lambda (= 0.5 \times 1.67 \times 10^{-6} \times \sin 42.1) = 5.6(0) \times 10^{-7} \text{ m (or 560 nm) **(1)**}$$

2

[9]

**10**

C

[1]

**11**

D

[1]

**12**

(a) same wavelength or frequency **(1)**  
(same phase or) constant phase difference **(1)**

2

- (b) (i) narrow slit gives wide diffraction **(1)**  
(to ensure that) both  $S_1$  and  $S_2$  are illuminated **(1)**
- (ii) slit S acts as a point source **(1)**  
 $S_1$  and  $S_2$  are illuminated from same source giving monochromatic/same  $\lambda$  **(1)**  
paths to  $S_1$  and  $S_2$  are of constant length giving constant phase difference **(1)**  
[or  $SS_1 = SS_2$  so waves are in phase]

Max 4  
QWC 1

- (c) graph to show:  
maxima of similar intensity to central maximum **(1)**  
[or some decrease in intensity outwards from centre]  
all fringes same width as central fringe **(1)**

2

[8]

**13**(a) (i) 0,  $2\pi$  or  $4\pi$  [or 0,  $360^\circ$  or  $720^\circ$ ] **(1)**(ii)  $4\lambda$  **(1)**(iii)  $\sin \theta = \frac{CE}{AC}$  **(1)**[or  $\sin \theta = \frac{BD}{AB}$ ]CE =  $4\lambda$  and AC =  $2d$  **(1)** (hence result)[or BD =  $2\lambda$  and AB =  $d$ ]

max 3

(b) (limiting case is when  $\theta = 90^\circ$  or  $\sin \theta = 1$ )

$$n \left( = \frac{d \sin \theta}{\lambda} \right) = \frac{2.22 \times 10^{-6} (\times 1)}{486 \times 10^{-9}} \text{ **(1)** } (= 4.6)$$

highest order is 4th **(1)**

2

**[5]****14**

B

**[1]****15**

A

**[1]****16**

C

**[1]****17**

D

**[1]****18**

(a) (i) vertical or parallel **(1)**  
 equally spaced **(1)**  
 black and yellow [or dark and light] bands **(1)**

$$(ii) \quad w \left( = \frac{\lambda D}{s} \right) = \frac{5.86 \times 10^{-7} \times 1.8}{0.36 \times 10^{-3}} \text{ **(1)**}$$

$$= 2.9 \times 10^{-3} \text{ m **(1)**}$$

$$\tan \theta = \frac{2 \times 2.9 \times 10^{-3}}{1.8} \text{ **(1)** gives } \theta = 0.18^\circ \text{ **(1)**}$$

(iii) narrower slits give more diffraction **(1)**  
 more overlap (so more fringes) **(1)**  
 fringes same width **(1)**

(max 8)

(b) (i)  $d = \frac{1}{400 \times 10^3}$  (1)

$$\frac{1}{400 \times 10^3} \times \sin \theta = 5.86 \times 10^{-7} \text{ (1)}$$

$$\theta = 13.6^\circ \text{ (1)}$$

(ii)  $\theta = 90^\circ$  and correctly used (1)

$$n = \frac{1}{400 \times 10^3 \times 5.86 \times 10^{-7}} = 4.3 \therefore \text{4th order (1)}$$

(5)

(c) brighter images (1)

large angles (1)

sharper (or narrower) lines (1)

(max 2)

[15]

19

(a) graph to show:

maxima of successively smaller intensity (1)

subsidiary maxima / minima equally spaced (1)

(at least two each side of central axis)

width of subsidiary sections half width of central section (1)

symmetrical pattern each side of central axis (1)

4

(b) (i) broader maxima or pattern (1) [or fringes wider apart]  
dimmer pattern (1)

(ii) maxima are closer (1) [or narrower fringes]  
green and dark regions (1)

max 3

[7]

20

(a) (i) (since  $d \sin \theta = n\lambda$ )  $d \sin 18.5^\circ = 632.8 \times 10^{-9}$  (1)

$$d = 1.99 \times 10^{-6} \text{ (1)}$$

$$\text{number of lines per metre} = \frac{1}{d} = 5.01 \times 10^5 \text{ (1)}$$

(ii)  $n\lambda = 1.99 \times 10^{-6} \sin 90^\circ$  (1)

$$n = -\frac{1.99}{0.6328} = 3.1(5) \text{ (1)}$$

hence highest order is third (1)

(6)

(b)  $\lambda_{\text{new}} = \frac{632.8 \times 10^{-9} \times \sin 17.2^\circ}{\sin 18.5^\circ}$  [or  $1.994 \times 10^{-8} \times \sin 17.2^\circ$ ] **(1)**  
 = 590 nm **(1)**

(2)

**[8]**

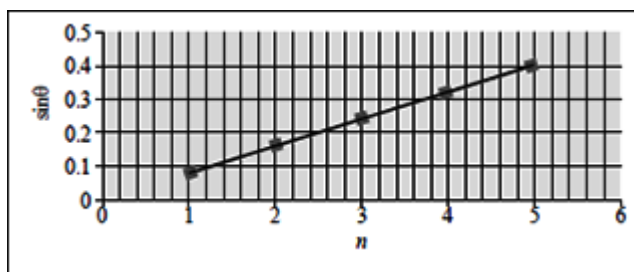
**21**

(a)

|   | $x / m$ | $\sin \theta$ |
|---|---------|---------------|
| 1 | 0.173   | 0.086         |
| 2 | 0.316   | 0.156         |
| 3 | 0.499   | 0.242         |
| 4 | 0.687   | 0.325         |
| 5 | 0.860   | 0.395         |

1

If angles only calculated 1 / 2



at least 4 points plotted correctly **(1)**

best straight line **(1)**

gradient calculated from suitable triangle, 50% of each axis **(1)**

correct value from readings **(1)**

appropriate use of  $d \sin \theta = n\lambda$  **(1)**

hence  $N$  (rulings per metre) =  $1.25 \times 10^5 \text{ m}^{-1}$  (1.1 to 1.4 ok) **(1)**

max 2 / 6 if no graph and more than one data set used correctly, 1 / 6 only one set

if tan calc but plotted as sin, mark as scheme

tan or distance plotted, 0 / 6

max 6

- (b) (i) maxima wider spaced [or pattern brighter] **(1)**  
 $\sin \theta$  or  $\theta$  increases with  $N$  [or light more concentrated] **(1)**
- (ii) maxima spacing less **(1)**  
 $\sin \theta$  or  $\theta$  decreases with  $\lambda$  [or statement] **(1)**

- (iii) maxima wider spaced [or pattern less bright] **(1)**  
 same  $\theta$  but larger  $D$  [or light more spread out] **(1)**

6

- (c) (i) waves in phase from **(1)**  
 any sensible ref to coherence **(1)**  
 whole number of wavelengths path difference **(1)**

- (ii) use of geometry to show that  $\sin \theta = \frac{\lambda}{d}$

max 3

**[15]**

**22**

(a)  $d = \left( \frac{n\lambda}{\sin \theta} \right) = \frac{(1 \times 7.00 \times 10^{-7})}{\sin 75^\circ} = 7.2 \times 10^{-7} \text{ m (accept 7.3) (1)}$

(1)

(b)  $\theta = \sin^{-1} \left( \frac{4.5 \times 10^{-7}}{1 \times 7.2 \times 10^{-7}} \right) = 39^\circ \text{ (accept } 38^\circ) \text{ (1)}$

(1)

(c)  $\frac{\lambda}{d} = \frac{7.5 \times 10^{-7}}{7.2 \times 10^{-7}} > 1 \text{ (or } \sin \theta > 1) \text{ (1)}$

$0^\circ$  (or straight through position) because no first order line **(1)**

(2)

**[4]**

**23**

(a) (i)  $20/47 = 0.43 \text{ s [0.426]}$

B1

- (ii) distance =  $340 \times 0.43$  *condone doubling for this mark*  
*[ $v = f\lambda$  solutions score zero]*  
*e.c.f. possible from 11 (a) (i)*

M1

$72 \text{ m [72.3] [73.1]}$

A1

- (b) (i)  $\lambda = 340/2400$  condone power of ten error in this mark

C1

$$= 0.14(2) \text{ m}$$

A1

- (ii) uses  $d = n\lambda/\sin \theta$   
*do not allow working from  $\sin \theta = \lambda/b$ ; this scores 0 overall*

B1

$$= 0.14[2]/\sin 28^\circ = 0.30(2) \text{ m e.c.f. possible}$$

B1

- (iii) calculates  $n = 2.14$  when  $\theta = 90^\circ$  *if states  $n \approx 2$  then allow this mark*

M1

highest  $n$  is 2

A1

24

- (i) use of  $(26 \pm 2)$  mm for  $2\theta$  **or**  $(13 \pm 1)$  mm for  $\theta$

M1

range  $2.60 \rightarrow 3.02$

A1

- (ii)  $n\lambda = d \sin \theta$  seen

M1

substitution with correct powers

$$1.20 \times 10^{-5} \rightarrow 1.40 \times 10^{-5}$$

A1

$1/d$  or number of lines  $\text{m}^{-1}$  calculated

$71400 \rightarrow 833300$  needs unit

B1

conversion to number of lines  $\text{mm}^{-1}$

$71(.4) \rightarrow 83(.3)$  needs unit

B1

[6]

25

- (a)  $1.06 \times 10^{-6}$  m

B1

1

- (b) use of  $n\lambda = d \sin \theta$  with  $n = 2$  and  $d =$  ans to (a)

C1

$$\lambda = 1.06 \times 10^{-6} \times \sin 55^\circ / 2$$

C1

$$4.34 \times 10^{-7} \text{ m}$$

A1

3

[4]

26

- (a) filament lamp / sun etc.

B1

(1)

(b) (i)  $d = 1.0 \times 10^{-4} \text{ m}$

C1

use of  $\lambda = d \sin \theta$  or substituted values

C1

$\theta_1 = 0.286^\circ / 0.29^\circ$

A1

(3)

(ii)  $\Delta\theta = 0.115^\circ$  (c.a.o.)

B1

(1)

(iii) width =  $4.0 \times 10^{-3} \text{ m}$  or  $3.9 \times 10^{-3} \text{ m}$  (e.c.f. for  $2 \times \sin$  (b(ii))  
or  $2 \times \tan$  (b(ii)); allow 1 s.f.)

B1

(1)

(c) lower intensity

C1

because energy spreads

C1

use or statement of inverse square law

C1

ratio 0.16 or falls by factor of 6.25 c.a.o.

A1

(4)

[10]