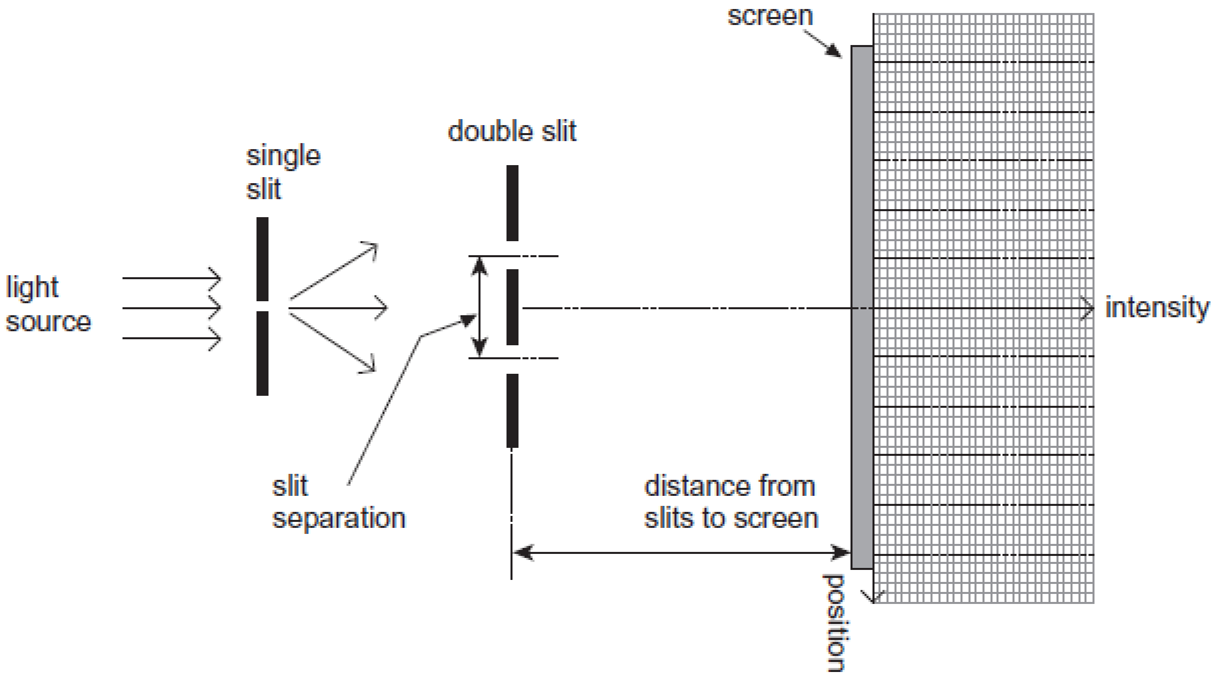
1 The diagram shows Young's double-slit experiment performed with a tungsten filament lamp as the light source.



not to scale

(a) On the axes in the diagram above, sketch a graph to show how the intensity varies with position for a **monochromatic** light source.

(2)

(b) (i) For an interference pattern to be observed the light has to be emitted by two **coherent sources**.
Explain what is meant by coherent sources.

____

____

____

____

(1)

(ii) Explain how the use of the single slit in the arrangement above makes the light from the two slits sufficiently coherent for fringes to be observed.

____

____

____

____

(1)

(iii) In this experiment light behaves as a wave.
Explain how the bright fringes are formed.

____

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____

____

(3)

(c) (i) A scientist carries out the Young double-slit experiment using a laser that emits violet light of wavelength 405 nm. The separation of the slits is 5.00×10^{-5} m.

Using a metre ruler the scientist measures the separation of two adjacent bright fringes in the central region of the pattern to be 4 mm.

Calculate the distance between the double slits and the screen.

distance = ____________________ m

(2)

(ii) Describe the change to the pattern seen on the screen when the violet laser is replaced by a green laser. Assume the brightness of the central maximum is the same for both lasers.

____

____

____

(1)

(iii) The scientist uses the same apparatus to measure the wavelength of visible electromagnetic radiation emitted by another laser.
Describe how he should change the way the apparatus is arranged and used in order to obtain an **accurate** value for the wavelength.

___

___

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___

___

(3)
(Total 13 marks)

2 A white-light source illuminates a diffraction grating that has 6.30×10^5 lines per metre. The light is incident normally on the grating.

(a) Show that adjacent lines in the grating are separated by a distance of about 0.0016 mm.

(1)

(b) The table below shows the diffracting angles measured from the normal for the visible spectral orders using this grating. The angles are given for the red and blue ends of each spectrum.

	First order	**Second order**	**Third order**
red	25.4°	59.0°	not possible
blue	15.0°	31.1°	50.0°

(i) Use the value for the first order diffracting angle to calculate the wavelength of the red light.

Wavelength of the red light ____________________

(3)

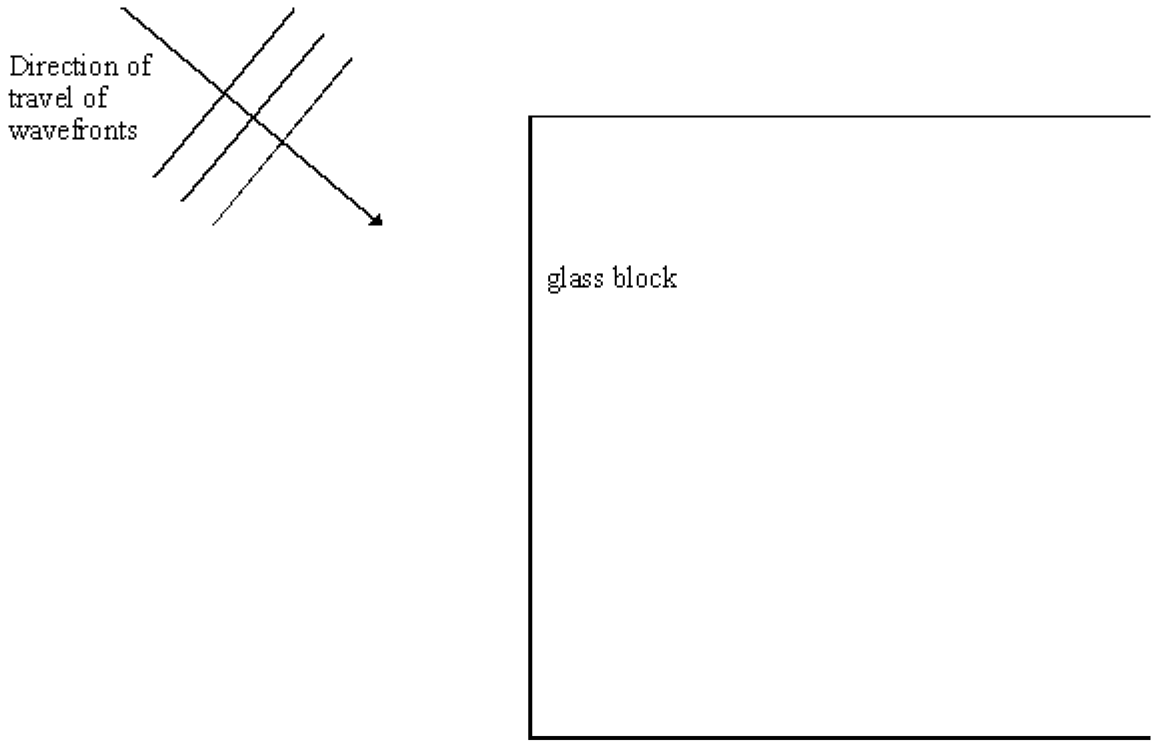
(ii) Describe carefully the appearance of the complete diffraction pattern on the screen. You may draw a sketch of the pattern to help your explanation if you choose.

(4)

(Total 8 marks)

3 The diagram below shows three wavefronts of light directed towards a glass block in the air. The direction of travel of these wavefronts is also shown.

Complete the diagram to show the position of these three wavefronts after partial reflection and refraction at the surface of the glass block.



(Total 3 marks)

4 (a) State the difference between *transverse* and *longitudinal* waves.

____

____

____

____

(2)

(b) State what is meant by *polarisation*.

____

____

____

____

(2)

(c) Explain why polarisation can be used to distinguish between transverse and longitudinal waves.

(2)

(Total 6 marks)

5 Polarization is a property of one type of wave.

(a) Circle below the type of wave that can be polarized.

transverse longitudinal

(1)

(b) Give **one** example of the type of wave that can be polarized.

(1)

(c) Explain why some waves can be polarized but others cannot. Space is provided for sketches should you wish to include them in your answer.

(3)

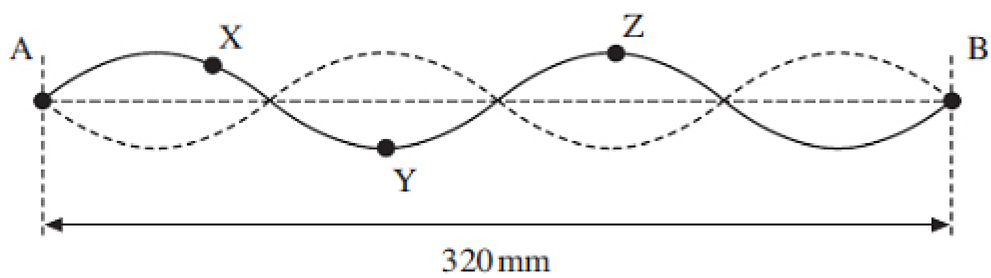
(Total 5 marks)

6

When a note is played on a violin, the sound it produces consists of the fundamental and many overtones.

Figure 1 shows the shape of the string for a stationary wave that corresponds to one of these overtones. The positions of maximum and zero displacement for one overtone are shown. Points **A** and **B** are fixed. Points **X**, **Y** and **Z** are points on the string.

Figure 1



(a) (i) Describe the motion of point **X**.

____

____

____

____

(2)

(ii) State the phase relationship between

X and **Y** ____

X and **Z** ____

(2)

(b) The frequency of this overtone is 780 Hz.

(i) Show that the speed of a progressive wave on this string is about 125 ms^{-1}.

(2)

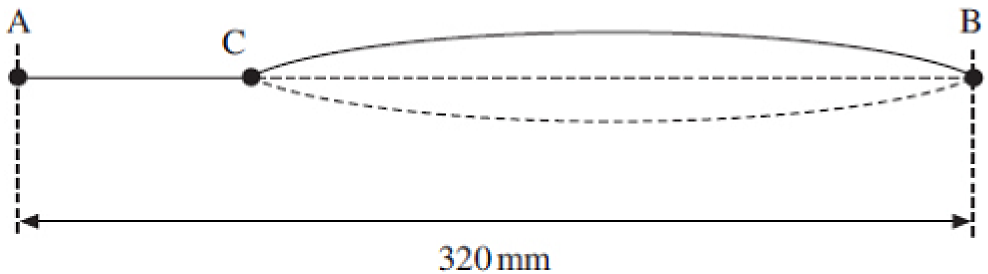
(ii) Calculate the time taken for the string at point **Z** to move from maximum displacement back to zero displacement.

answer = ____________________ s

(3)

(c) The violinist presses on the string at **C** to shorten the part of the string that vibrates. **Figure 2** shows the string between **C** and **B** vibrating in its fundamental mode. The length of the whole string is 320 mm and the distance between **C** and **B** is 240 mm.

Figure 2



(i) State the name given to the point on the wave midway between **C** and **B**.

____

(1)

(ii) Calculate the wavelength of this stationary wave.

answer = ____________________ m

(2)

(iii) Calculate the frequency of this fundamental mode. The speed of the progressive wave remains at 125 ms^{-1}.

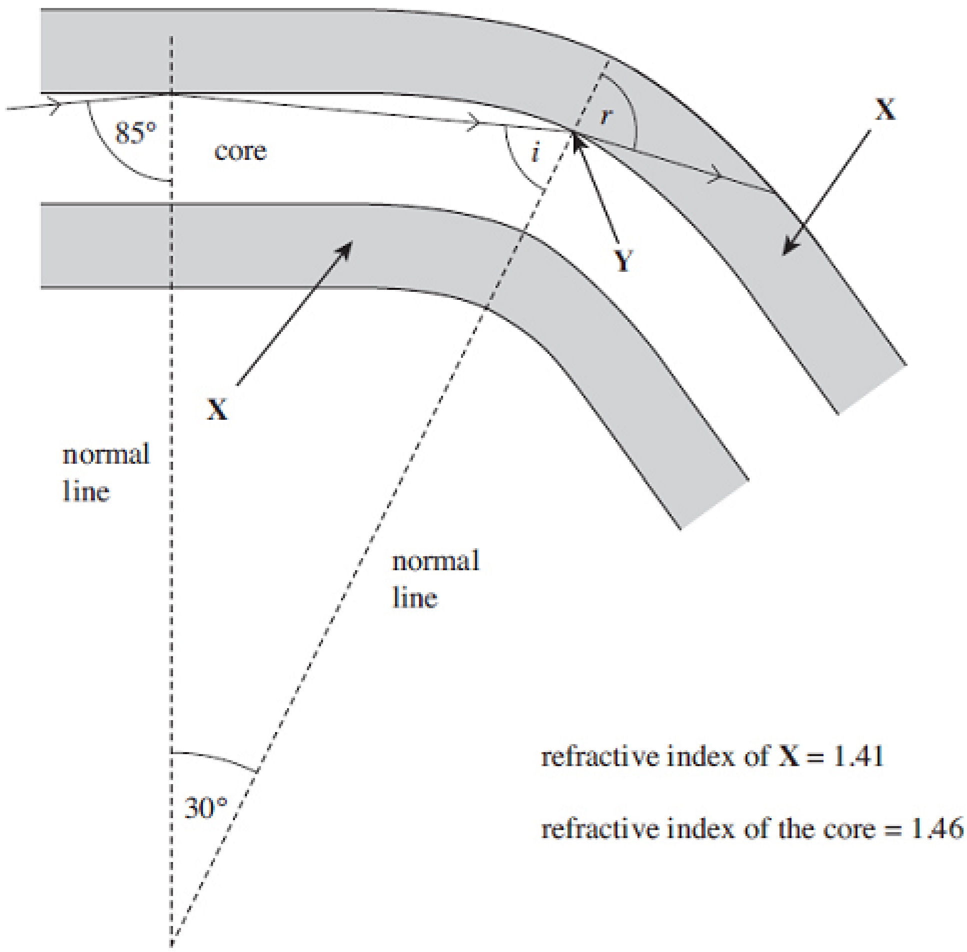
answer = ____________________Hz

(1)

(Total 13 marks)

7 **Figure 1** shows a cross-section through an optical fibre used for communications.

Figure 1



(a) (i) Name the part of the fibre labelled **X**.

____

(1)

(ii) Calculate the critical angle for the boundary between the core and **X**.

answer = ____________________ degrees

(2)

(b) (i) The ray leaves the core at **Y**. At this point the fibre has been bent through an angle of 30° as shown in **Figure 1**.

Calculate the value of the angle *i*.

answer = ____________________degrees

(1)

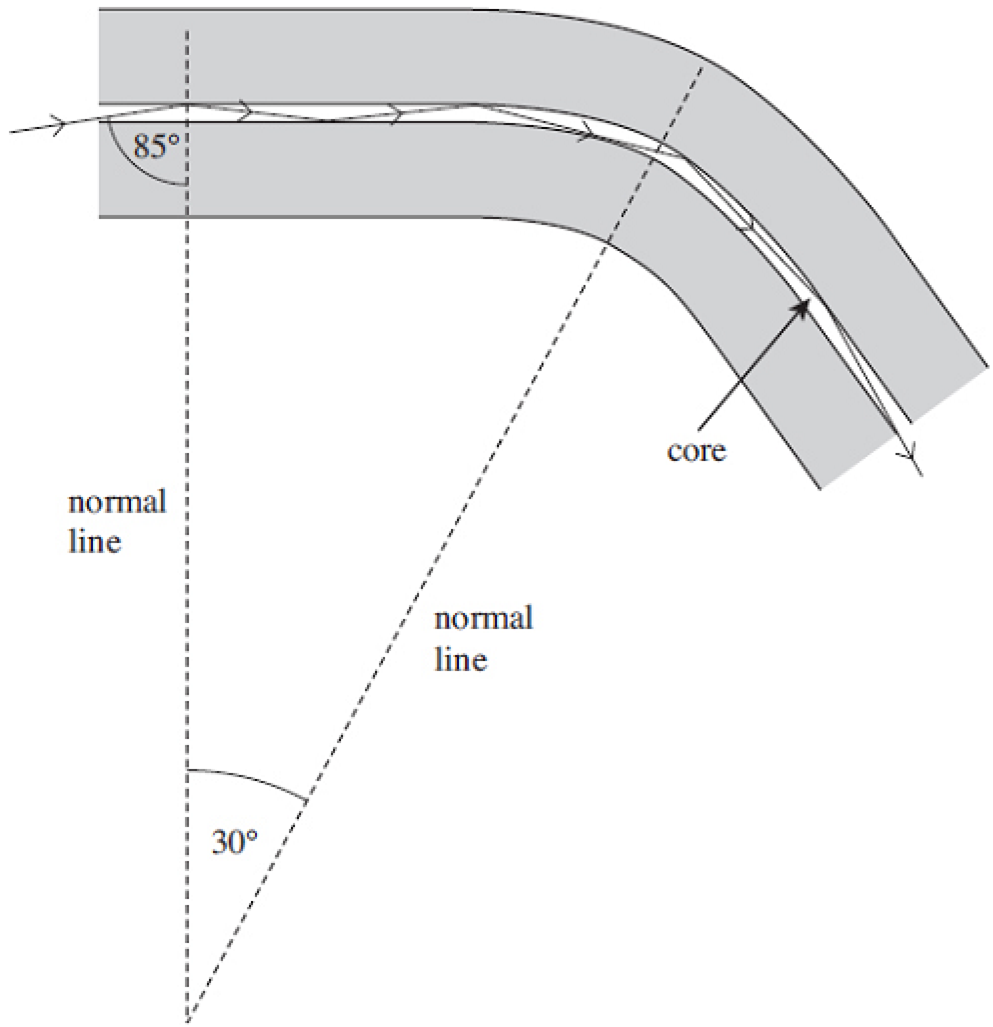
(ii) Calculate the angle *r*.

answer = ____________________degrees

(2)

(c) The core of another fibre is made with a smaller diameter than the first, as shown in **Figure 2**. The curvature is the same and the path of a ray of light is shown.

Figure 2



(c) State and explain **one** advantage associated with a smaller diameter core.

___

___

___

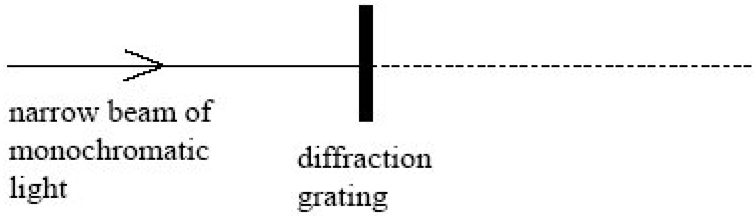
___

___

(2)

(Total 8 marks)

8 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 1.67×10^{-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°.

Calculate the wavelength of this light source.

answer ____________________ m

(2)

(Total 9 marks)

9 (a) A double slit interference experiment is set up in a laboratory using a source of yellow monochromatic light of wavelength 5.86×10^{-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.

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

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

(8)

(b) Light of wavelength 5.86×10^{-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.

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

____

____

____

(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.

____

____

____

(2)

(Total 15 marks)

10 The intensity of a sound is 1.9×10^{-8} W m^{-2} at a distance of 0.25 km from the source. Calculate the intensity of the sound at a distance of 0.75 km from the source.

Intensity of sound ____________________

(Total 3 marks)

11 Light from a laser has a wavelength of 6.30×10^{-7} m. When the laser light is incident normally on a diffraction grating the first order maximum is produced at an angle of 12°.

(a) Calculate the spacing between the lines on the grating.

spacing of lines ____________________

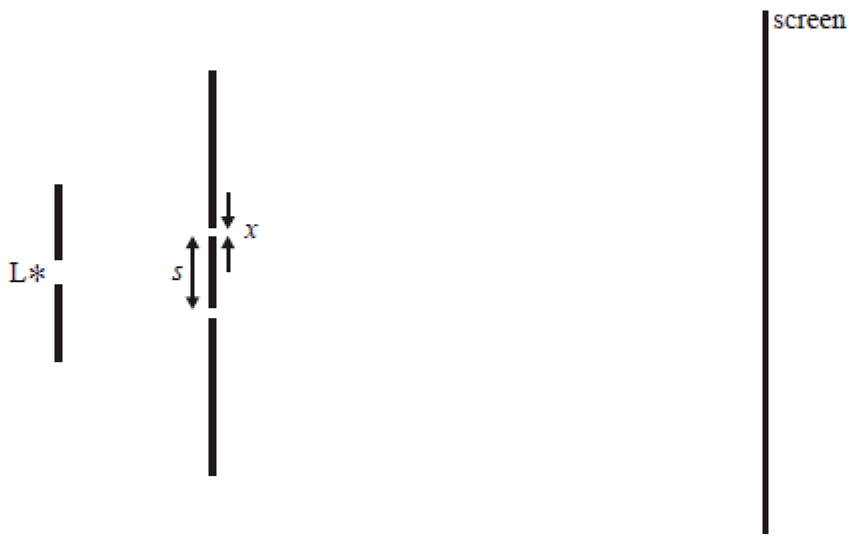
(2)

(b) Calculate the number of positions of maximum light intensity that are produced when the laser light is incident on the grating.
Show your reasoning clearly.

number of positions ____________________

(3)
(Total 5 marks)

12



In a double slit system used to produce interference fringes, the separation of the slits is s and the width of each slit is x. L is a source of monochromatic light. Which one of the following changes would **decrease** the separation of the fringes seen on the screen?

A moving the screen closer to the double slits

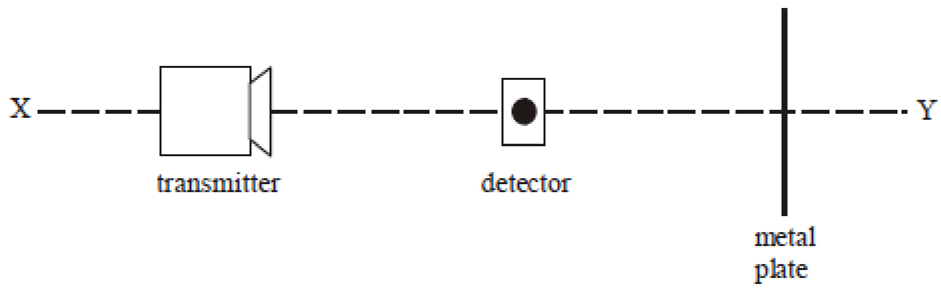
B decreasing the width, x, of each slit, but keeping s constant

C decreasing the separation, s, of the slits

D exchanging L for a monochromatic source of longer wavelength

(Total 1 mark)

13 A microwave transmitter is used to direct microwaves of wavelength 30 mm along a line XY. A metal plate is positioned at right angles to XY with its mid-point on the line, as shown.



When a detector is moved gradually along XY, its reading alternates between maxima and minima. Which one of the following statements is **not** correct?

A The distance between two minima could be 15 mm.

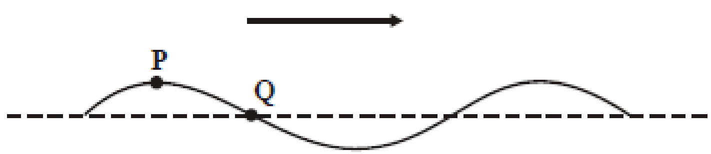
B The distance between two maxima could be 30 mm.

C The distance between a minimum and a maximum could be 30 mm.

D The distance between a minimum and a maximum could be 37.5 mm.

(Total 1 mark)

14 The diagram shows a snapshot of a wave on a rope travelling from left to right.

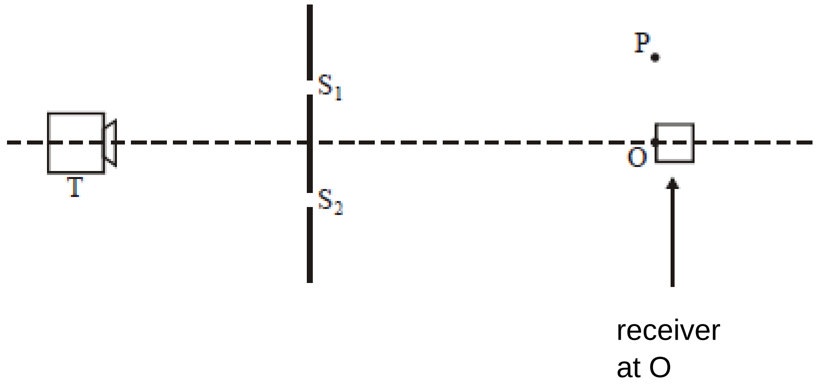


At the instant shown, point **P** is at maximum displacement and point **Q** is at zero displacement. Which one of the following lines, **A** to **D**, in the table correctly describes the motion of **P** and **Q** in the next half-cycle?

	P	**Q**
A	falls then rises	rises
B	falls then rises	rises then falls
C	falls	falls
D	falls	rises then falls

(Total 1 mark)

15 The diagram shows a microwave transmitter T which directs microwaves of wavelength eat two slits S_1 and S_2 formed by metal plates. The microwaves that pass through the two slits are detected by a receiver.



When the receiver is moved to P from O, which is equidistant from S_1 and S_2, the signal received decreases from a maximum to a minimum. Which one of the following statements is a correct deduction from this observation?

A The path difference $S_1O - S_2O = 0.5\,\lambda$

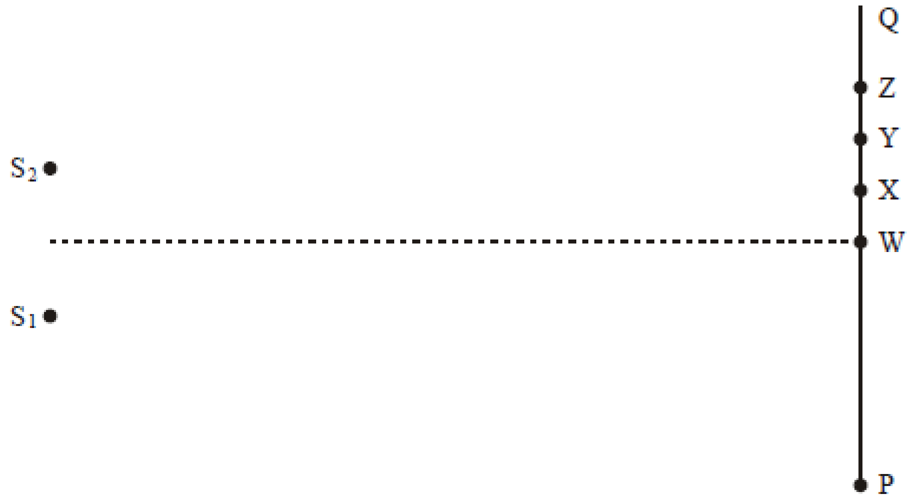
B The path difference $S_1O - S_2O = \lambda$

C The path difference $S_1P - S_2P = 0.5\,\lambda$

D The path difference $S_1P - S_2P = \lambda$

(Total 1 mark)

16



Point sources of sound of the same frequency are placed at S_1 and S_2. When a sound detector is slowly moved along the line PQ, consecutive maxima of sound intensity are detected at W and Y and consecutive minima at X and Z. Which one of the following is a correct expression for the wavelength of the sound?

A $S_1X – S_1W$

B $S_1Y – S_1X$

C $S_1X – S_2X$

D $S_1Y – S_2Y$

(Total 1 mark)

1 (a) uniform width peaks ✓ (accurate to within ± one division)

peaks need to be rounded ie not triangular

the minima do not need to be exactly zero

a collection of peaks of constant amplitude or amplitude decreasing away from central peak ✓

pattern must look symmetrical by eye

condone errors towards the edge of the pattern

double width centre peak total mark = 0

2

(b) (i) constant / fixed / same phase relationship / difference (and same frequency / wavelength) ✓

in phase is not enough for the mark

1

(ii) single slit acts as a point / single source diffracting / spreading light to both slits ✓
OR
the path lengths between the single slit and the double slits are constant / the same / fixed ✓

1

(iii) superposition of waves from two slits ✓

phrase 'constructive superposition' = 2 marks

diffraction (patterns) from both slits overlap (and interfere constructively) ✓ (this mark may come from a diagram)

constructive interference / reinforcement (at bright fringe)
peaks meet peaks / troughs meet troughs ✓ (any reference to antinode will lose this mark)

waves from each slit meet in phase
OR path difference = $n\lambda$ ✓

4 max 3

(c) (i) $D = \frac{ws}{\lambda} = \frac{0.004 \times 5.0\,10^{-5}}{405 \times 10^{-9}}$ ✓ **do not penalise any incorrect powers of ten for this mark**
= 0.5 (m) ✓ (0.4938 m)

numbers can be substituted into the equation using any form

note 0.50 m is wrong because of a rounding error

full marks available for answer only

2

(ii) fringes further apart or fringe / pattern has a greater width / is wider ✓

ignore any incorrect reasoning

changes to green is not enough for mark

1

(iii) increase D ✓

measure across more than 2 maxima ✓

several / few implies more than two

added detail which includes ✓
explaining that when D is increased then w increases
Or
repeat the reading with a changed distance D or using different numbers of fringes or measuring across different pairs of (adjacent) fringes
Or
explaining how either of the first two points improves / reduces the percentage error.

no mark for darkened room

3

[13]

2 (a) Separation = 1/630000

B1

1

(b) (i) quote $n\lambda = d \sin\theta$

C1

$\lambda = 1.59 \times 10^{-6} \times \sin(25.4)$

C1

$= 6.8 \times 10^{-7}$ m or 6.8×10^{-4} mm

A1

3

(ii) Central maximum/zeroth order mentioned

B1

Central maximum is white

B1

Describe/draw 1st/2nd orders colours in correct order

B1

Third order overlap
symmetry of pattern
dispersion change
fainter away from centre

B1

max 4

[8]

3 reflection wavefront direction sensible

B1

refraction wavefront direction sensible

B1

one pair of wavefronts correctly spaced

B1

[3]

4 (a) transverse: vibration / displacement / disturbance not movement is perpendicular to direction of travel **B1**

longitudinal: vibration / displacement / disturbance not movement is parallel to (same) direction of travel **B1**

C1 for idea of transverse and longitudinal being perpendicular **(2)**

(b) restriction of vibration / idea of how polarisation occurs **B1**

single plane / same orientation – diagram may help **B1** **(2)**

(c) only transverse can be polarised / longitudinal cannot **B1**

idea of being able to restrict vibration to single plane
or longitudinal not being perpendicular to motion
or longitudinal vibrating in direction of travel **B1** **(2)**

[6]

5 (a) Transverse **B1**

(b) correct example of transverse wave
(e.g. light / electromagnetic / radio etc. allow photon b.o.d.) **B1**

(c) [transverse] displacement vector perpendicular to energy direction [accept 'direction of motion'] **B1**

[longitudinal] vector parallel to energy direction **B1**

polarisation is restriction of displacement vector to one plane OWTTE

[allow any or all marks on clear diagram] **B1**

[5]

6 (a) (i) oscillates / vibrates ✓

(allow goes up and down / side to side / etc, <u>repeatedly, continuously, etc</u>)

about <u>equilibrium</u> position / perpendicularly to central line ✓

2

(ii) X and Y: antiphase / 180 (degrees out of phase) / π (radians out of phase) ✓

X and Z: in phase / zero (degrees) / 2π (radians) ✓

2

(b) (i) $v = f\lambda$

= 780 x 0.32 / 2 or **780 x 0.16 OR 780 x 320 / 2** or **780 x 160** ✓

THIS IS AN INDEPENDENT MARK

= 124.8 ✓ (m s^{-1}) correct 4 sig fig answer must be seen

2

(ii) ¼ cycle ✓

T = 1 / 780 OR = 1.28×10^{-3} ✓

$0.25 \times 1.28 \times 10^{-3}$

= 3.2×10^{-4} (s) ✓

Allow correct alternative approach using distance of 0.04m ✓

travelled by progressive wave in ¼ cycle divided by speed.

0.04 /125 ✓ = 3.2×10^{-4} (s) ✓

3

(c) (i) antinode ✓

1

(ii) 2 x 0.240 ✓

= 0.48 m ✓ '480m' gets 1 mark out of 2

2

(iii) ($f = v/\lambda$ = 124.8 or 125 / 0.48) = **260** (Hz) ecf from cii ✓

1

[13]

7 (a) (i) cladding ✓

1

(ii) sin θ_c = 1.41/1.46 ✓

θ_c= 75.0 (°) (74.96) ✓

2

(b) (i) 65 (degrees) ✓

1

(ii) 1.46 sin 65 = 1.41 sin r **or** sin r = 0.93845 ✓ ecf bi

r = 70 ✓ (degrees) (69.79) ecf bi

2

(c) Two from:

- less light is lost
- better quality signal / less distortion
- increased probability of TIR
- Less change of angle between each reflection
- reflects more times (in a given length of fibre) keeping (incident) angle large(r than critical angle)
- (angle of incidence is) less likely to fall below the critical angle
- less refraction out of the core
- improved data transfer / information / data / signal carried quicker
- less multipath dispersion (smearing / overlap of pulses)

✓✓

2

[8]

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

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

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

7.07×10^{8} if nm used **(1)**

$\theta = 45.0°$ **(1)** (accept 45°)

(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 3rd 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 **(1)**

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

7

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

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

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

2

[9]

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

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

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

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

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

$\theta = 13.6°$ **(1)**

(ii) $\theta = 90°$ and correctly used **(1)**

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

(5)

(c) brighter images **(1)**
large angles **(1)**
sharper (or narrower) lines **(1)**

(max 2)

[15]

10 use of inverse-square law

C1

3 × distance so 1 / 9 × intensity (or equivalent calc)

C1

$1.9 \times 10^{-8} / 9 = 2.11 \times 10^{-9}$ Wm^{-2}

A1

[3]

11 (a) $d \sin \theta = n \lambda$ or $d \sin 12 = 6.3 \times 10^{-7}$

C1

3.0×10^{-6} m

A1

2

(b) $n \sin 90 = (\leq)\ 3.0 \times 10^{-6} / 6.3 \times 10^{-7}$ or $n = 4.8$

Allow for approach using different n values even if unsuccessful

C1

number of orders visible = 4

A1

Total maxima = twice their maximum order + 1

B1

3

[5]

12 A

[1]

13 C

[1]

14 D

[1]

15 C

[1]

16 D

[1]

Examiner reports

1 This was a discriminating question throughout all its parts. Very few students answered this question without error in some part. A majority of students simply reproduced the single slit diffraction pattern with a double width centre fringe for (a). These students were not awarded any marks. Most of the answers that did score some marks rarely produced graphs that were very smooth with peaks falling in height following the expected profile. All sorts of sharp edges and cusps were drawn and the spacing between fringes were rarely uniform.

In (b)(i) the answer, ‘in phase’, features just as often as, ‘constant phase difference’. Weaker students did not refer to phase but concentrated on the frequency or wavelength being the same thereby missing the main point. In (b)(ii) a majority of students did not understand the function of the single slit and simply gave an answer that couples together some themes suggested earlier in the question. So a common response was, ‘used to make the light coherent as it has the same wavelength’. Students gave a much better response to (b)(iii) where a majority discussed the waves being in phase and constructive interference, although some had a few issues about how to express a phase difference. Many referred to a phase as being a proportion of a wavelength. As in a previous question the words superposition was confused with superimposition. In the explanation of how the bright fringes are formed, very few explained how the pattern is positioned where the two diffraction patterns of the double slits overlap. The weaker students instead discussed how to set up the apparatus in great detail which must have taken some time in using up half the answer space. In essence they only described what was shown.

In (c)(i) most students knew which equation to use but only half managed to calculate the correct answer. Some used a factor of 2 with the width spacing. Others did not rearrange the equation properly or made errors in powers of 10. Many students seem to make a guess in answering (c)(ii). Just as many students correctly said the pattern or fringes get wider as said they get narrower. Additionally many students explained the change by referring to the wavelength change. However in many cases the explanation contradicted what they gave as their answer.

Students did not do well in the final part of this question, (c)(iii). A majority tried to change the apparatus rather than change how it was used. These students did score some marks by getting a mark for increasing the double slit to screen distance along with a majority of the others. Fewer students scored the other marks available but referring to measuring across more fringes was the next regularly gained mark. Some students failed to gain marks unnecessarily by the way they phrased their answers, an example being, ‘Change D to make it easier to measure’.

2 This question examined topics in diffraction-grating theory.

(a) Many could show successfully how the grating spacing was calculated.

(b) (i) Again many could carry out the simple calculation accurately. Common errors were to treat *n* in the equation $n\lambda = \sin\theta$ not as ‘1’ but as 6.30×10^5 lines per metre, and to carry through the calculation in millimetres, but express the answer in metres.

(ii) Judging by the poor quality of many answer, few candidates have ever seen a diffraction grating pattern during their course of study. There were a number of possible scoring points available featuring the appearance of the central maximum, the order of colours (which could be deduced from the question), the overlap of orders, and so on. Only a few candidates scored more than one or two marks.

3 Drawings were again very poor. Examiners awarded marks not only for correct directions of the wavefronts but also for an awareness that wavefront spacings change in refraction and remain unchanged in reflection. Candidates really must take more trouble over these relatively simple drawings if they are not to throw away marks.

4

(a) Most candidates were able to show that they knew and understood the differences between transverse and longitudinal waves. Weaker candidates confused their answers by giving unclear statements such as *'…transverse waves move at right angles to their direction of travel whilst longitudinal move in a parallel direction'*.

(b) Answers were often unclear and candidates tended to focus on the polarisation of light waves, often going on to talk about the effect of crossed polaroids in their answers. Most candidates recognised that transverse waves can be polarised but there was some confusion about why longitudinal waves cannot.

(c) Answers were often unclear and candidates tended to focus on the polarisation of light waves, often going on to talk about the effect of crossed polaroids in their answers. Most candidates recognised that transverse waves can be polarised but there was some confusion about why longitudinal waves cannot.

5

(a) Almost all candidates knew that transverse waves could be polarised.

(b) Almost all could give a clear, correct example of a wave that can be polarised.

(c) Explanations of why some waves can be polarised were weaker. Not only were the descriptions of the wave types muddled and poor, but many failed to describe clearly why longitudinal waves cannot be polarised. A large number would have helped themselves by drawing clear well *labelled* diagrams.

6 Part (a)(i) was almost universally misinterpreted due to a similar question appearing on a previous paper. Many students interpreted the question as 'describe the motion over the next cycle'. Those who did this often failed to point out that there was a continuing oscillation taking place. Part (a)(ii) was very poorly answered which was a surprise. A common answer was 'out of phase' for X and Y which is not equivalent to 'antiphase'. Phase was often given in terms of number of wavelengths, e.g. ½λ. There was little understanding of the difference between phase difference along a progressive wave and a stationary wave. Many had measured the fraction of a wavelength between the points and converted this into an angle as you would for a progressive wave. It is suggested that phase difference along a stationary wave be demonstrated by referring to the many simulations available.

Part (b)(i) presented few problems for students. In part (b)(ii) many students did 1/780 and obtained the time for one complete cycle but did not recognise that they needed to divide by 4 to get the time for ¼ of a cycle. A significant number thought that the time between maximum displacement and reaching the equilibrium position was half a cycle. Some divided 780 by 4 which makes the answer 8 times greater than it should be.

For part (c)(i) most students got 'antinode' but a significant number put 'node'/ 'amplitude'/ 'max displacement' / 'stationary wave' / 'equilibrium' / 'maxima'. Part (c)(ii) presented few problems for students. In part (c)(iii) quite a few students left this blank because they were unable to answer the previous question. However, many of those who scored the mark did so by using an incorrect answer to (c)(ii). Students should be encouraged not to give up; the final part of a question is not necessarily the hardest.

7 In part (a)(i) a significant number of students did not know 'cladding' and in part (a)(ii) the majority got this one correct. However, a significant number had their calculators in radians mode and gained 1 mark for the correct working but got a wrong answer of 1.31. Some rounded prematurely (eg 1.41/1.46 = 0.97 which leads to an answer of 76° rather than 75°). When using the inverse sine function it is important that the value used has not been rounded to less than 4sf.

Quite a few students gave an answer of 85−30 = 55° or 90−30 = 60° for part (b)(i). In part (b)(ii) most students do very well on Snell's law questions. Those who got the wrong answer for (b)(i) often got full marks here with the error carried forward taken into account. Some did get the refractive indices the wrong way round or omitted the 1.46 – presumably thinking they were calculating a critical angle for a glass / air boundary.

In part (c) many students thought that rays would refract 'when the critical angle is exceeded'; perhaps associating a large angle with being 'too big'. Many thought that a ray will travel further in a wide core. It will actually travel the same distance if the angle is the same.

8 There were common mistakes to part (a) (i), such as failing to put n = 2. Some candidates thought n was the refractive index and for this reason put n = 1. A significant number did not convert from nm to m. Part (a) (ii) was done very well by the majority of candidates, either by substituting in 90° or n = 3. Most were successful in finding the wavelength to part (b).

9 Descriptions of the fringes in part (a)(i) were generally poor. In spite of the emphasis on the word **vertical**, hardly any candidates referred to the vertical lines which result. Furthermore, simple references to dark and bright equally-spaced bands were very rare. Confusion with the single diffraction pattern was common and some candidates contradicted themselves by referring to equally- spaced fringes at the same time as showing a diagram of the single slit pattern. Some of the descriptions made it difficult to believe that the writer had ever seen double slit interference fringes.

The large majority of candidates correctly calculated the fringe separation but failed to determine the angle. The word 'angle' frequently triggered the diffraction grating equation and, for those candidates who did attempt a simple geometrical calculation, many calculated the angle only to the first bright fringe and not the second. Such candidates penalised themselves by failing to read the question carefully. Several candidates who had calculated d correctly were quite prepared to offer a maximum order of thousands as their answer to part (b)(ii).

Answers to part (a)(iii) showed a general weak understanding of the relative parts played by interference and diffraction in this part of the question. One group of candidates failed to score any marks because they confused variation of slit width with slit separation and gave their answer in terms of the latter. For those candidates who did consider the narrowing of each slit, many scored only a single mark for recognising that the light at each slit will be diffracted through a larger angle. Although answers were often given in rather vague terms such as "more diffraction". To gain full credit, it was necessary to refer to the greater area of overlap of the diffracted beams and to recognise that more fringes are seen in this increased area because the fringe width is unchanged. Hardly any candidates made the last of these two points.

Calculations in parts (b)(i) and (b)(ii) were done well and many candidates scored full marks. Common errors in part (b)(i) included incorrect conversion of units from 400 lines per millimetre, poor arithmetic and the often seen confusion between the grating constant, d, and the number of rulings per unit length, N.

Good answers to part (c) were rare and the two systems were not often compared from a position of secure knowledge. Very few candidates were able to state that the grating is designed to produce fewer lines which are brighter and more widely spaced. Indeed, many candidates stated that the grating produced more fringes. Most answers concentrated on the accuracy of the readings rather than on how the readings were to be obtained. Answers were, in general, very vague.

10 There were many highly competent and successful solutions to this simple question. However, there were many significant figure and unit penalties – all the more surprising since the unit of the answer was mentioned in the question itself.

11 (a) Some incorrectly quoted and used sin $\theta = \lambda / b$ but most used the appropriate formula. Forgetting a unit cost some the second mark.

(b) Relatively few gained all three marks here. Those who were on the right track obtained 4.8 and rounded down to 4 orders but then forgot about the symmetry of the pattern and the central maximum. There was a significant proportion who simply divided 180° by 12°.