Mark schemes

Q1.

(a) Max 2 from: $_1$✓$_2$✓

links constructive interference as cause of bright fringe $_a$✓

correct reference to zero phase difference or 'in phase' $_b$✓

path difference = 2*d* **OR** (*n* + 0.5)λ seen $_c$✓

2*d* = (*n* ± 0.5)λ $_3$✓

3

(b) determines *s* from $\frac{5}{11}$

OR

substitutes their *s* into $\frac{t}{l} = \frac{\lambda}{2s}$ with values for *l* and *λ* $_1$✓

$_1$✓ Expect s = 0.45 mm. Condone POT errors.
$_1$✓ All substitutions must be in consistent units of length.
$_1$✓ Must be some attempt to determine s. Reject use of 5.0 mm.

3.9×10^{-5} (m) $_2$✓

2

(c) Allow either $_1$✓ or $_2$✓ if there is no reference to frequency, but not both:

If no other mark, credit use of 1.3 e.g. c_{water} = 2.3 × 10^8 m/s.

wave speed decreases (and frequency is constant) $_1$✓

(frequency is constant so) wavelength decreases $_2$✓

$_2$✓ May see calculated λ_{water} = 454 nm

s will decrease, with reference to $\frac{t}{l} = \frac{\lambda}{2s}$ $_3$✓

$_3$✓ Only awarded if values of both t and l are stated, or a clear reference to both of them being constant.
$_3$✓ Allow ecf from an incorrect $_2$✓
$_3$✓ Reject references to e.g. double-slit equation.

3

[8]

Q2.

(a) ray through A links to ray in B

AND

ray in B horizontal by eye ✓

Ignore any arrow directions.

1

(b) Conclusion consistent with their **Figure 1**✓

*Answer must be consistent with their **Figure 1.***

For a correct diagram expect to see B has greater refractive index / A has lower refractive index'

Supported by consideration of their angles of incidence and refraction at AB boundary ✓

For a correct diagram expect to see 'at AB boundary angle of incidence > angle of refraction' OR 'at AB boundary the ray bends towards the normal'.

2

(c) appropriate application described ✓

how the grating is used must be described e.g 'used to determine λ of named light source' or 'used to identify elements in a sample'

Examples:

To analyse chemical composition (of a sample)

To stabilise/filter laser light

To provide a monochromatic source/select a particular wavelength of light

In optical encoders for high-precision motor control

Spread evenly the light from e-readers

Condone:

to identify (some) authentic bank notes

applications associated with entertainment eg light shows/diffraction glasses.

application associated with analysis of the light from the Sun

1

(d) MAX 2 from ✓✓

- λ read from spectrum = 380 nm
- use of $d \sin\theta = n \times$ (their λ)
- use of $G = \frac{1}{d}$

Ignore POT error in MP1 & MP2.

Accept answer in range 377.5 - 382.5 nm.

'Use of' means clear substitution of n, θ and their λ or rearrangement of equation to give $d = \frac{n\lambda}{\sin\theta}$.

If n not seen, assume that n = 1.

Expect to see 8.04 × 10^{-7} m for d

to give 1.2 × 10^6 (m^{-1}) ✓

MP2 and MP3 may be seen together

Calculator value range: 1.251790×10^6 m^{-1} to 1.2435547×10^6 m^{-1} to 1.235427×10^6 m^{-1}

3

(e) Argument involving $\sin\theta = nG\lambda$ or equivalent comparing effect of $n = 2$ and $G' = 2G$ ✓

Appreciation that angular separations would be the same for both options ✓

For MP3, allow maxima are better defined in option 2

Discussion suggesting option 2 / 2*G* should be used, as $n = 2$ spectrum could overlap with other orders obscuring absorption lines ✓

Alternative for MP3: idea that 2G should be used as the second-order spectrum would be dimmer - allow reverse argument that 2G first order would be brighter.

3

[10]

Q3.

(a) **A** and **B** are in antiphase or π rad out of phase or 180° out of phase ✓

*Condone: **A** and **B** are **completely** out of phase.*
Allow a description of one being a peak when other is a trough.

(difference in distance travelled =) 178 (nm) or 2 x 89 (nm)

OR

A and **B** travel different distances

OR

There is a path difference

OR

states the path difference = $(n + \frac{1}{2})\lambda$ ✓

The path difference is half of a wavelength (of the light in the thin layer) ✓

***MP2 Alternative**: thickness of layer is ¼ of wavelength (of light in layer) **or** 89 nm is a ¼ of the wavelength (of light in layer) **or** journey through layer is ½ of wavelength (of light in layer)*

Condone path difference = nλ where n ≠ 0

***MP2 and MP3** time-based alternative: **MP2** it takes (some) time for **B** to travel through medium (before meets **A**)*

MP3

time taken to travel this (half wavelength) equals half of the period.

Do not accept half of a wavelength out of phase.

3

(b) Correctly reads off 0.93 and (-)0.37

Allow a range of 0.90 to 0.95 for A's read off and a range of (-)0.35 to (-)0.40 for B's read off.

Or

Adds their two read-offs provided one is negative✓

Allows values of 0.9 and (-)0.4 for read-offs.

Look to graph for read-offs.

0.56 ✓

Answer in range 0.59 to 0.53

Answer to 2 sf answer here.

*An answer of 0.6 or 0.5 scores **1 mark maximum.***

2

(c) Use of $T = \frac{1}{f}$

OR

Fraction of a cycle determined:

$\frac{137}{360}$ or $\frac{8\ (\text{squares})}{21(.3)\ (\text{squares})}$ or 0.38 seen✓

(T=) $\frac{1}{4.72 \times 10^{14}}$ *OR (T =) 2.12 × 10^{-15} (s) seen*

*Condone use of their T in **MP2***

Equation has been rearranged and t would be the subject.

*Condone use of their decimal fraction of a cycle in **MP2**.*

Expect to see decimal fraction of 0.38 or 0.37

Answer to at least 2 significant figures

(t =) $\frac{137}{360}$ × T seen

OR

(t =) $\frac{8\ (\text{squares})}{21(.3)\ (\text{squares})}$ × T seen

OR

(t =) $\frac{137}{360} \times \frac{1}{4.72 \times 10^{14}}$ *seen* ✓

(t =) 8.1×10^{-16} (s) ✓ must include valid supporting work

Alternative:

MP1 *finds wavelength above surface (636 nm) and determines fraction of wavelength corresponding to fraction of cycle (242 nm)*

MP2 *divides the fraction of the wavelength by the speed of the light above the surface.*

MP3 *answer to at least 2 significant figures.*

Accept any answer to 2 significant figures that would round to 8.1×10^{-16} *(s).*

Use of $\lambda = 356$ *nm is incorrect. Only* ***MP1*** *is available for fraction of a cycle.*

• *Do not allow answers where* $c = f\lambda$ *is used to determine* $c = 1.68 \times 10^{8}$ *m* s^{-1}.

• *Do not allow use* $\frac{135.5}{356} \times T$ *OR* $\frac{135.5}{356} \times \frac{1}{4.72 \times 10^{14}}$ *in MP2*

3

(d) Use of speed = $\frac{\text{distance}}{\text{time}} = \frac{2 \times 89 \times 10^{-9}}{8.06 \times 10^{-16}}$ ✓

(Speed =) 2.2×10^{8} (m s^{-1}) ✓

Use of $n_s = \frac{c}{c_s}$ ✓

n_s = 1.36 or 1.4 ✓

Their incorrect t must round to 8 x 10^{-16} ***(s). for ecf.***

Condone POT in MP1 ***OR*** *condone use of 89 nm for distance. (Will give an answer for n of 2.72 or 2.7)*

Condone use of their c_s *in MP3*

Where 3 sf answer seen, range is 1.35 to 1.37

OR

Use of $\frac{t}{T} \times \lambda = 178 \times 10^{-9}$ ✓

λ = 468 nm ✓

Use of $c_s = f\lambda$ and $n_s = \frac{c}{c_s}$ ✓

n_s = 1.36 or 1.4✓

Allow 2 marks maximum for an answer for n of 1.79 or 1.8 with working. (Error in use of of λ = 356 nm) .

*Condone as an **ECF on MP4.***

*Condone POT in MP1 **OR** condone use of 89 nm for fraction of wavelength. (Will give an answer for n of 2.72 or 2.7)*

Condone use of their λ in MP3

Where 3sf answer seen, range is 1.35 to 1.37

OR

Use of $\frac{137}{360} \times \lambda = 178 \times 10^{-9}$ ✓

λ = 468 nm ✓

Use of $c_s = f\lambda$ and $n_s = \frac{c}{c_s}$ ✓

n_s = 1.36 or 1.4✓

*Condone POT in MP1 **OR** condone use of 89 nm for fraction of wavelength. (Will give an answer for n of 2.72 or 2.7)*

Condone use of their λ in MP3

Where 3sf answer seen, range is 1.35 to 1.37

Allow an ECF in MP4 for one arithmetical error / transcription error.

Where $t = 8 \times 10^{-16}$ is used:

Speed = 2.225×10^{8} m s^{-1}

Wavelength in layer = 471 nm

Refractive index = 1.35

4

[12]

Q4.

(a) ray is incident along/at the normal owtte ✓

Allow perpendicular/90° to the surface/block.
Allow 'angle of incidence is 0°'.
Reject 'towards the normal'.

1

(b) correct use of Snell's law ✓

21° ✓

Expect to see 1.84 sin15 = 1.33 sinθ
Calculator value for θ is 20.9814°

2

(c) (intensity increases because) total internal reflection occurs owtte ✓

Reject 'more total internal reflection occurs'.
'There is more reflection' is insufficient.

idea that the lower intensity to left of **T** is due to partial reflection ✓

MP2 must be in terms of reflected, not refracted, light.
Allow answers in terms of x.

2

(d) **T** will move to right **OR** *x* will increase ✓

(because) critical angle will increase ✓

MP1 requires some relevant justification
e.g. ratio $\frac{n_2}{n_1}$ *will be closer to 1.*

2

(e) uses tan $\theta = \frac{69}{60}$ to calculate correct θ_c to 2 sf min ✓

MP1: Calculator value for θ_c *is 48.99091°*

uses sin $\theta_c = \frac{n}{1.84}$ to determine refractive index ✓

MP2: Allow ecf from MP1. Expect n = 1.388.

uses their refractive index to at least 4 sf to obtain the concentration ✓

MP3: Allow ecf from MP2. Expect 33.5%.

3

[10]

Q5.

(a) Uses

$\sin c = \frac{1}{n}$

to get 1.51 ✓

Must see relevant work to award the mark.
Minimum 3 sf must be seen

1

(b) (Each) angle of incidence is 45° (at 2nd and 3rd surfaces)

AND

total internal reflection occurs / which is greater than the critical angle. ✓

Angle of incidence as ray leaves block is 0°

OR

The ray leaves along the normal (and so the ray emerges parallel to the incident ray). ✓

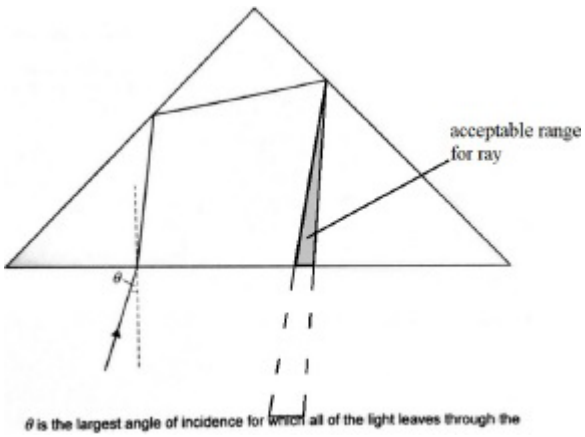
2

(c) Only (totally internally) reflected ray seen at 2nd reflecting boundary ✓

Reflected ray parallel to first refracted ray (by eye)✓

Ray leaves parallel to initial ray (by eye) ✓

For MP2:



3

(d) Angle of incidence at 2nd reflecting boundary = 41.5° ✓

MP1 is an identification of angle at 2nd reflecting boundary

Angle of reflection at 1st reflecting boundary = 48.5° ✓

MP2 is (90°- their angle at 2nd reflecting boundary)

Angle of refraction at entry = (90° - 45° - 41.5°) = 3.5° ✓

MP3 is (45° - their angle at 2nd reflecting boundary)

Use of n = 1.5 and Snell's law to give 5.3° to at least 2 sf ✓

Accept answer that rounds to 5.3°

The identification of their angles can be inferred from their working or diagram. Simply writing 90° - 41.5° = 48.5° does not get a mark on its own.

4

(e) Using 60° prism (Fig 3) does not work because:

- light would not leave the prism at the original angle ✓
- idea that light will escape from second reflection ✓

A smaller n (Fig 4) does not work because:

- larger critical angle ✓
- which would reduce the value of θ ✓

Suggestion that the design would work limits the mark to Max 1 for that design.

Alternative for MP2

Light would no longer be totally internally reflected at second reflection

OR

angle of incidence at second reflection is now less than the critical angle

4

[14]

Q6.

(a) Use of $f = \frac{1}{T}$ or (T =) 2.63×10^{-15} (s) seen

or

number of waves = $\frac{6 \times 10^{-9}}{\text{their } T}$

or

$6 \times 10^{-9} \times 3.8 \times 10^{14}$ ✓

Condone POT error in MP1

Use of $f = \frac{1}{T}$ *is* f *subsituted and formula rearranged to make* T *the subject.*

$\frac{1}{6 \times 10^{-9}}$ *is not sufficient for use of* $f = \frac{1}{T}$

Alternative for MP1:

calculates the length of a pulse ($6 \times 10^{-9} \times 3 \times 10^{8}$ = *1.8 m)* ***and*** *calculates the wavelength* = $\frac{3 \times 10^{8}}{3.8 \times 10^{14}}$ = 7.9×10^{-7}

OR

Determines maximum number of pulses per second $\frac{1}{6 \times 10^{-9}}$ ***and*** *divides number of cycles per second by the number of pulses per second. That is:*

$\frac{3.8 \times 10^{14}}{\frac{1}{6 \times 10^{-9}}}$ or $\frac{3.8 \times 10^{14}}{1.67 \times 10^{8}}$

2.3×10^{6} ✓

Calculator display 2280000

Unsupported answers with POT error 1 mark

2

(b) Use of speed = $\frac{\text{distance}}{\text{time}}$

by substituting for speed (3×10^8 ms^{-1}) and time (10.7×10^{-6} s) **and** making distance the subject

OR

Use of speed = $\frac{\text{distance}}{\text{time}}$ **and** divides their distance by 2

OR

(time =) $\frac{10.7 \times 10^{-6}}{2}$ / (time =) 5.35×10^{-6} s ✓

Condone POT error on MP1

An answer = 3.2(1) × 10³ (m) obtains 1 mark with working (allow POT on this compensatory mark)

Alternative calculation for total distance: Multiples the wavelength (7.9 x 10⁻⁷ m) by the number of waves in 10.7 μs $(\frac{10.7 \times 10^{-6}}{2.63 \times 10^{-15}})$:

That is $\frac{3 \times 10^8}{3.8 \times 10^{14}} \times \frac{10.7 \times 10^{-6}}{2.63 \times 10^{-15}}$ /

$\frac{3 \times 10^8}{3.8 \times 10^{14}} \times \frac{10.7 \times 10^{-6}}{\frac{1}{3.8 \times 10^{14}}}$ / 7.9 x $10^{-7} \times \frac{10.7 \times 10^{-6}}{2.63 \times 10^{-15}}$

/ 7.9 × 10⁻⁷ × 4.066 × 10⁹ seen

OR

Multiples the wavelength (7.9 × 10⁻⁷ m) by the number of waves in 10.7 μs . (10.7 × 10⁻⁶ × f) where f = 3.8 × 10¹⁴

That is:

7.9 × 10⁻⁷ × 10.7 × 10⁻⁶ × 3.8 × 10¹⁴ /

$\frac{3 \times 10^8}{3.8 \times 10^{14}}$ *× 10.7 × 10⁻⁶ × 3.8 × 10¹⁴ seen*

1.6 × 10³ (m) ✓

(Calculator displays 1605)

(c) Use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$ ✓ by substitution

*Condone use of θ_1 = **38**° provided n_{air} = 1 : need to see an explicit statement 1 × sin θ_1 **and** answer = 1.0(2).*

Allow their θ_1 from an attempt to find 90 −38 in use of

Allow 62 or 42 for θ_1 without supporting evidence in use of

Do not allow θ_1 = 90° in use of

Allow use of $1n_2$ = $\frac{\sin i}{\sin r}$ or $\frac{n_2}{n_1} = \frac{\sin i}{\sin r}$

or n = $\frac{\sin i}{\sin r}$

*must see i = their θ_1 **and** r = 37° for use of any of these*

*Do not allow this method for $i = \theta_1$= **38**° unless answer = 1.0(2) **and***

either

$1n2 / \frac{n2}{n1}$ *is seen as subject*

or

n is subject and there is an explicit statement that n_{air} = 1

(n_2 =) 1.3(1) ✓

2

(d) Attempted use of $n = \frac{C}{C_s}$

Expect to see $c_s = 2.3 \times 10^8$ (m s^{-1})

Ecf from part (c) in use of $n = \frac{C}{C_s}$

Or

use of their $c_s = f\lambda$ ✓

Condone their c_s in use of $c = f\lambda$

6.0×10^{-7} (m) or 6.1×10^{-7} (m) ✓

Ecf from part (c)

Answer = $7.7(4) \times 10^{-7}$ (m) for $n = 1.02$

Or $7.7(2) \times 10^{-7}$ (m) for $n = 1.02$ where no rounding on ecf

Alternative

Divides wavelength in air by the refractive index ✓

*Answer = 7.89×10^{-7} (m) for $n = 1.0$ (only condone this answer where $n = 1$ or $n = 1.0$ seen as ecf from part **(c)***

6.0×10^{-7} (m) or 6.1×10^{-7} (m) ✓

Expect to see 6.03×10^{-7} or 6.07×10^{-7}

Maximum of 1 mark where speed in ice sheet is more than speed of light in a vacuum is seen.

Penalise 1 significant figure

2

[8]

Q7.

(a) attempts to calculate energy stored during 2.6 hr period

OR

attempts to calculate average output power during 12 hr period using their energy stored $_1$ ✓

Correctly rounded answer gains both marks. (Calculator value is = 2.16666667)

For $_1$ ✓ stored energy = 93.6 kJ

For $_1$ ✓ condone use of t in hours. (2.6 hr = 9360 s; 12 hr = 43200 s)

2.2 (W) $_2$ ✓

If no other mark given, award 1 mark for calculating charge transfer during 2.6 hr period as 18.7 kC

2

(b) Max 2 from: ✓ ✓

microwaves are transverse; sound are longitudinal;

microwaves have higher frequency than sound;

microwaves can be polarised but sound can't;

microwaves can travel through a vacuum but sound can't/requires a medium **OR** sound are mechanical waves but microwaves are EM waves

Apply list principle. Do not allow reference to applications e.g. cooking food.

For first point, allow weak descriptions in terms of parallel and perpendicular oscillations/vibrations with direction of energy transfer.

2

(c) fixed/constant phase difference $_1$ ✓

same frequency $_2$ ✓

For $_1$ ✓ do not accept "in phase" or fixed <u>path</u> difference.

For $_2$ ✓ condone "same wavelength".

Ignore reference to other features e.g. amplitude or type of wave.

2

(d) evaluates **AM** from $\mathbf{AM}^2 = 8.00^2 + 0.34^2$

OR evaluates **BM** from $\mathbf{BM}^2 = 8.00^2 + 2.14^2$ ✓

$8.28 - 8.01 = 0.27\ (\text{m})$ ✓

No credit for using double-slit equation.

*Expect 8.01 (m) for **AM** and 8.28 (m) for **BM***

2

(e) statement that path difference = $\lambda/2$ **OR** uses wavelength = 2 × their **part (d)** answer $_1$ ✓

Evaluates $\dfrac{340}{\text{correct } \lambda}\ (\text{Hz})$ $_2$ ✓

For $_1$ ✓ expect to see 0.54 or 0.60 m for wavelength

*For $_2$ ✓ expect 570 Hz (from 0.3 m) **OR** 630 Hz (from 0.27 m) **OR** 620 Hz (from 0.274 m).*

If no other mark given, allow 1130 Hz or 1260 Hz. for 1 mark.

No credit for using double-slit equation.

2

[10]

Q8.

(a) As angle of refraction greater than angle of incidence with reference to Snell's law / n = sin i ÷ sin r

OR

light bends away from normal when it speeds up ✓

(Therefore $n_A > n_B$)

1

(b) Calculation of angle of incidence = 90° − 43° = 47° ✓

Use of Snell's law to give angle of refraction = 61(.4)° cao ✓

MP1 may be seen on diagram
Calculator value: 61.357 115 7

2

(c) Use of sin c = 1/n to get c = 48°

OR

i = (180° – 43° − 61.4° =) 76° ✓

Other calculation and i greater than c therefore tir ✓

Ray reflecting off **P** to land where the top of the n of 'not to scale' label meets the glass surface ✓

Condone 77° but not 75°
No ecf from MP1 to MP2
Allow a range:

3

[6]