

Mark schemes

1.

- (a) One wavelength✓

Accept λ

1

- (b) Light from slits overlap / undergo diffraction✓

Path difference is a whole number of wavelengths

Or

Arrive at screen in phase / zero phase difference ✓

(Meet and) undergo superposition / waves superpose✓

*If no other mark awarded allow **one** mark for:*

interfere constructively / Produces reinforcement / produces constructive interference

3

- (c) Pointer **A** and CD ✓

Condone:

smallest wavelength and greatest slit spacing

(Smallest) angular spread for each order ($\theta_{\min}$) is given by $\sin \theta_{(\min)} = \frac{n \lambda}{d}$

OR

Greatest number of maxima is given by $n_{\max} = \frac{d}{\lambda}$ ✓

Max 1 mark for:

An argument that links spacing to slit width and its effect on diffraction.

2

- (d) use of $n \lambda = d \sin \theta$ ✓

For example, where:

$$n = 1, \lambda = 6.36 \times 10^{-7} \text{ m and } d = 1.6 \times 10^{-6} \text{ m } (\theta = 23^\circ)$$

or

$$n = 2, \lambda = 6.36 \times 10^{-7} \text{ m and } d = 1.6 \times 10^{-6} \text{ m } (\theta = 53^\circ)$$

use of $\tan \theta = r / 15$

or

adds θ_2 and θ_1 and compares to 90°

or

adds θ_2 and θ_2 and compares to 90°

or

adds θ_1 and θ_1 and compares to 90° ✓

Allow use of $\tan \theta = r / 15$

for any combination of θ , r and 15 where unknown has been made subject.

No, can see 4 (bright spots) ✓

$\theta = 45^\circ$ and 3 bright spots therefore yes is a maximum of max 2 marks

Allow use of $n = \frac{d}{\lambda}$ where they have reached a conclusion for 1 mark maximum.

3

[9]

2.

- (a) Spreading of pulse / parts of a pulse take different times to travel through the fibre / pulse broadening ✓

Do not credit material dispersion.

owtte

Due to different paths through the optical fibre / due to entering the optical fibre at different angles ✓

Accept a diagram showing different paths.

2

- (b) $\text{speed } (= \frac{\text{distance}}{\text{time}}) = \frac{10 \times 10^3}{5.225 \times 10^{-5}} \quad \checkmark \quad (= 1.91 \times 10^8)$

1

- (c) Reads off $\sin \theta_R = 0.3391$

or

use of $n_1 \sin \theta_1 = n_2 \sin \theta_2$ ✓

Use of $n = \frac{c}{c_s}$ seen ✓

With their $\sin \theta_R$

(Refractive index of core = 1.47)

Allow use of their refractive index where c_s is the subject of the formula

$$c_s = 2.03 \times 10^8 \text{ ✓}$$

Alternative:

Reads off $\sin \theta_R = 0.3391$

or

$$\theta = 19.8^\circ \text{ ✓}$$

$$c_s \cos 19.8 = 1.9 \times 10^8 \text{ ✓}$$

$$c_s = 2.03 \times 10^8 \text{ ✓}$$

Allow finding θ_R for their read off

Allow use of their θ_R

3

- (d) The refractive index of core for blue light is greater than the refractive index for red / The refractive index of core for red light is less than the refractive index for blue ✓

Max 1 mark for stating that the refractive indices are different because their speeds are different

MP1 can come from graph or prior knowledge

The speed of the blue light is less than the speed of the red light and travel the same distance / The speed of the red light is greater than the speed of the blue light and travel the same distance ✓

2

- (e) the blue now travels a shorter distance than the red light (compared to (d))✓

or

the red light now travels a greater distance than the blue light (compared to (d))✓

or

the difference between the blue's velocity parallel to the central axis and the red's velocity (parallel to the central axis) has decreased (compared to (d)). ✓

Allow: now travel different distances whereas previously travelled the same distance.

or

the difference between the horizontal velocity of the red light and the horizontal velocity of the blue light has decreased (compared to (d)).✓

1

[9]

3.

D

70°

[1]

4.

C

using monochromatic light of higher frequency

[1]

5.

- (a) Speed = $3.0 \times 10^8 / 1.47$
 = $2.0(4) \times 10^8 \text{ m s}^{-1}$ ✓

Do not accept 1 sf answer

1

- (b) Critical angle calculation ✓

$$\sin C = n_{\text{clad}} / n_{\text{core}} = 1.41 / 1.47 = 0.96$$

$$\text{critical angle} = 73.6^\circ$$

Angle of refraction calculation✓

$$r = 90 - C = 16.4^\circ$$

Do not give MP2 if calculated answer is given as A

Angle of incidence calculation ✓ $\sin(i) = 1.47 \sin(r)$

$$i = 24.5^\circ$$

Allow 2 sf answer; allow 24.6°

3

- (c) Correct path of light drawn showing partial reflection and transmission of ray when it encounters the boundary ✓

Angle of incidence on core–cladding boundary decreases✓

And will now be less than critical angle ✓

(Some light will escape/be refracted into cladding

Some light will continue)

If the diagram is not annotated and no other mark is given, 1 mark can be given for correct description of partial reflection.

3

[7]

6.

C

433 nm

[1]

7.

- (a) reads off λ_p 1✓

for 1✓ condone POT;

expect $\lambda_p = 635 \pm 2$ (nm) /

$635 \pm 0.02 \times 10^{-9} / 6.35 \pm 0.02 \times 10^{-7}$ (m)

allow evidence of working on **Figure 1**

1

use of $n \times$ their $\lambda_p = d \sin \theta$ 2✓

for 2✓ accept subject n with no / incomplete substitution, eg

$$N = \frac{\sin \theta}{n \times \lambda_p}$$

OR

subject d and full substitution, eg

$$d = \frac{5 \times \text{their } \lambda_p}{\sin 76.3} / 5.15 \times \text{their } \lambda_p \quad 5.15 \times \text{their } \lambda_p$$

OR

correct result $d = 3.27 (\times 10^{-6} \text{ (m)})$;

allow ECF in λ_p including POT;

allow recognisable d / 2 sf intermediate result

3

$$N = \left(\frac{1}{d} = \frac{1}{3.27 \times 10^{-6}} \right) = 3.06 \times 10^5 \quad 3✓$$

for 3✓ accept ≥ 3 sf in range 3.05 to 3.07×10^5 OR

$$N = \frac{0.194}{\text{their } \lambda_p} \quad (\text{allow ECF for } \lambda_p \text{ out of range but}$$

not if due to POT)

1

- (b) identifies an appropriate physical characteristic that makes the measurement of the (5th) maximum more difficult ✓

take 'it' to be the 5th maximum / peak

(centre difficult to locate because)

(5th) 'maximum is wider' / 'peak less pronounced' / 'less defined' or worse;

allow 'maximum more spread out' / 'less pronounced'

OR

maximum 'is fainter' / 'less bright' / 'intensity reduced';

reject 'not as clear'

OR

(cannot use edges to determine location of centre because)

'whole maximum (may be) not visible' / 'can't see edges'

OR

(L_R produces a range of wavelengths so)

4th and 5th / adjacent fringes may overlap

1

- (c) extrapolation of linear region of the L_R characteristic $_1✓$

for $_1✓$ reads off where a ruled extrapolation to the linear region of the L_R characteristic reaches the horizontal axis

the line must be free from discontinuities; condone a ruled dashed line

condone tangent meeting curve at $I \geq 10$ mA

V_A for L_R in range 1.91 to 1.93 (V) $_2✓$

for $_2✓ > 3$ sf acceptable if rounding to 3 sf

2

- (d) any fully correct calculation of the Planck constant $_1✓$

for $_1✓$ allow 2 sf

use of $c = 3(.00) \times 10^8$ AND $e = 1.6(0) \times 10^{-19}$

AND EITHER

V_A from (c) AND λ_p in range 620 to 650 nm / ECF their λ_p from (a)

OR

$V_A = 2.00$ AND λ_p in range 550 to 580 nm;

calculates mean of two valid calculations of the Planck constant;

result in range 6.10 to 6.50×10^{-34} (J s) $_2✓$

for $_2✓$ Planck constant result rounding to correct 3 sf

(check very carefully working leading to data booklet value 6.63×10^{-34})

1

- (e) V_F corresponding to $I_F = 21$ mA read from L_R graph in **Figure 3**;

use of $V_F = 2.01$ (V) leading to $R = 195$ (Ω) earns both marks

calculates R from $\frac{6.1 - \text{their } V_F}{21(0 \times 10^{-3})}$ $1\checkmark$

*for $1\checkmark$ accept evidence of working on **Figure 3** condone 2 sf eg $V_F = 2.0$ (V)*

allow POT error for I_F

1

$$R = 195 \text{ } (\Omega) \text{ from } \frac{6.10 - 2.01}{21(0) \times 10^{-3}} = 195 \text{ } 2\checkmark \quad 195 \text{ } 2\checkmark$$

for $2\checkmark$ evidence to show use of $V_F = 2.01 \pm 0.01$ (V) must be seen, ie allow

$$\frac{6.10 - 2.00}{21(0) \times 10^{-3}} = 195 \text{ OR } \frac{6.10 - 2.02}{21(0) \times 10^{-3}} = 194$$

1

[10]

8.

B

[1]

9.

- (a) Max one from: $\checkmark$
internal ray is a radius (of the block)

OR

internal ray travels along a normal

OR

ray meets (glass-air) boundary at 90°

OR

angle of incidence is zero

(so angle of emergence/refraction is zero)

1

- (b) Straight line ruled from centre of protractor through **ABC** $\checkmark$

*for $1\checkmark$ line must be reasonable and must pass through intersection of the cross-wires and must not pass above the centre of **A** or below the centre of **B***

Takes a pair of readings: 24 or 66; and angle consistent with their line $\checkmark$

Must be between 0° and 90°

Use of Snell's Law with their angles $\checkmark$

1.48 or 1.52 $\checkmark$

Must be a positive value to 3 sf.

4

- (c) 1.47 or 1.471 $\checkmark$

Reject 1.5 or >4 sf; ignore any unit written

1

(d) 0.08 (mm) ✓

Only acceptable answer

1

(e) Calculates one percentage uncertainty

 For ₁✓ allow ecf from (d); expected answers are

 % uncertainty in $(R_2 - R_0) =$

$$100 \times \frac{0.08}{14.28} = 0.56(0)\%$$

 % uncertainty in $(R_2 - R_1) =$

$$100 \times \frac{0.08}{9.71} = 0.82(4)\%$$

OR

Calculates max or min value ✓

$$n_{\min} = \frac{14.28 - 0.08}{9.71 + 0.08} = 1.45(0);$$

$$n_{\max} = \frac{14.28 + 0.08}{9.71 - 0.08} = 1.49(1);$$

Adds their percentage uncertainties

OR

 attempt to use percentage $n = \frac{0.5(\max - \min)}{1.47} \times 100$ ✓

 Ecf for ₂✓ from wrong percentage uncertainties or wrong max or min values

1.4(%) ✓

Condone 3 or 4 sf

3

[10]

10.

A

[1]

11.

 (a) Attempt to resolve **A** or **B** eg $430 \times \cos 35^\circ$ or $T_B \times \cos 12^\circ$ ✓

360 (N) ✓

 If no other mark given, allow $430 \times \sin 35^\circ = T_B \times \sin 12^\circ$ to give 1190 N for 1 mark.

2

 (b) Substitution of F and A into Young modulus or stress equation ✓

 4.4×10^{-2} (m) ✓

Condone POT error for Young modulus

2

- (c) Angle of **A** decreases or angle of **B** increases ✓

Accept references to 35° or 12°

Any correct application of trig or geometry to the situation

(eg $T_B/T_A = \cos\theta_A/\cos\theta_B$ so as θ_A decreases, $\cos\theta_A$ increases, $\cos\theta_B$ decreases, so T_B/T_A increases)

OR

eventually θ_B will equal 35° , $\theta_A = 12^\circ$ so forces will be reversed (as system is symmetrical)

OR

sum of vertical components remains unchanged and vertical component of tension becomes less as angle **A** decreases ✓

*Allow idea that more of the weight is supported by **B***

T_A decreases, following some relevant discussion ✓

3

- (d) Greater rate occurs when pulses are shorter (in time)/less modal dispersion ✓

Allow reverse arguments

Smaller diameter (leads to less modal dispersion) means smaller range of path lengths ✓

Accept idea of fewer reflections

X is more suitable because narrower core leads to lower modal dispersion or reduced pulse broadening ✓

3

[10]

12.

C

[1]

13.

- (a) Understanding that for coherence sources must have same frequency/wavelength AND constant phase difference. ✓

And that this achieved by both speakers being connected to same signal (generator). ✓

2

- (b) The sound waves from the two speakers superpose (at a point) ✓

*Do **not** accept 'interfere' or 'superimpose' for 'superpose'*

Accept for MP1 waves adding together/combine at a point (e.g. point A) for 'superpose'.

Do not accept diagram.

At A (and B) the two waves are in phase/ have zero phase difference (and a maximum is produced) ✓

Moving away from A introduces a path difference/phase difference/waves are out of phase (and amplitude decreases) ✓

(Moving on towards B the waves move back in phase)

Award MP3 for formation of minimum/destructive interference due to (odd number of) half wavelength path difference/ π / 180° phase difference/ antiphase.

3

- (c) Clear evidence of use of Pythagoras ✓

Correct calculation of either length PB or QB ✓

$$PB = (2.25^2 + (0.95 - 0.3/2)^2)^{1/2} = 2.39 \text{ m}$$

$$QB = (2.25^2 + (0.95 + 0.3/2)^2)^{1/2} = 2.50 \text{ m}$$

(Path difference =) QB – PB either numerically or algebraically ✓

$$= 0.11 \text{ (0.12) m}$$

If ws/D used to give 0.13 (m) reward with 1 mark

3

- (d) (Path difference = one wavelength)

Use of speed = frequency $\times$ wavelength to give

$$\text{Speed} = 2960 \times 0.12 = 360 \text{ m s}^{-1} \text{ ✓}$$

Working or equation must be seen.

Condone use of 0.10 m or 0.11 m or 0.127m or 0.13 m

$$0.10 \text{ gives } 300 \text{ (296) m s}^{-1}$$

$$0.11 \text{ gives } 330 \text{ (325.6) m s}^{-1}$$

$$0.127 \text{ gives } 376 \text{ m s}^{-1}$$

$$0.13 \text{ gives } 380 \text{ (385) m s}^{-1}$$

1

- (e) Wavelength (gradually) increases. ✓

So that path difference at C gets closer to one wavelength ✓

Alternative for MP2:

Separation of maxima (along line AB) increases ✓

(Amplitude of) sound will get larger/louder as waves move in phase (then smaller/quieter). ✓

Alternatives for MP3:

Maximum moves (from B) towards C so amplitude of sound gets larger/louder (then quieter).

OR

Maximum moves further along path/beyond C so amplitude of sound gets quieter ✓

3

[12]

14.

D

[1]

15.

B

[1]

16.

- (a) Max 2 from: ✓ ✓

(Because) the refractive index of water is greater than air

(and) the angle of incidence is greater than the critical angle

total internal reflection (of laser beam) occurs

Allow optical density for refractive index.

Allow answer given as a diagram.

2

- (b) Use of $n = \frac{c}{c_s}$ eg $c_s = \frac{3.00 \times 10^8}{1.33}$ ✓

2.26×10^8 (m s⁻¹) ✓

3 sf answer from some relevant working ✓

3

- (c) 49 (°) ✓

Do not allow 1 sf answer.

1

- (d) The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question

Mark	Criteria
6	Both functions and dispersion problems discussed. No significant error or inconsistency.
5	Both functions and dispersion problems discussed. There may be some significant error or inconsistency.
4	Functions or dispersion problems described. No significant error or inconsistency.
3	Functions or dispersion problems described. There may be some significant error or inconsistency.
2	Both X and Y named and a function of one given; or A function of X and Y given, but only one named
1	X and Y identified by name or function
0	No relevant analysis

Level 2 max if dispersion modes confused in descriptions.

The following statements are likely to be present.

Names

X is Core

Y is Cladding

Functions

X:

Propagates/Guides the wave/light

By TIR

(with) low attenuation/absorption

Refractive index of core > cladding

Y:

Protects core from damage

Prevents cross talk between touching fibres

Provides 'clean' boundary for TIR

Dispersion problems

Both: *Cause pulse broadening/limited bandwidth*

Material: *different wavelengths have different speeds due to different refractive indices within the core – use monochromatic beam*

Modal: *different paths have different lengths so effective time along fibre differs – use single-mode fibre (narrow core/small Δn between core and cladding)*

- (e) Max 2 from: ✓ ✓

Allow responses shown on diagram.

Light may encounter impurities at different positions/angles

Light may encounter different number of impurities

Allow "different impurities".

Light may encounter different sizes of impurities

Angle of incidence may become less than critical angle

Don't accept "critical angle changes"

Bending may cause cracks in the core/cladding

Light may be refracted (more/differently)

2

- (f) Transverse – displacement/oscillations/vibrations at right angles/(perpendicular) to direction of energy transfer ✓

Condone "direction of wave" once.

1 mark for correct reference to difference in polarisation.

Longitudinal – displacement/oscillations/vibrations along/(parallel to) direction of energy transfer ✓

Treat references to P and S wave as neutral.

2

[16]

17.

A

[1]

18.

A

[1]

19.

- (a) MAX 2

Uncertainty in one/each reading is 1 mm ₁✓

Allow the uncertainty in (reading) the position of a spot is 1 mm. ₁✓

OR

The measurement involves making two readings / there are two uncertainties (to be considered) in this measurement ₁✓

Owtte

Difficulty / uncertainty in locating (exact) position of (centre of) spot ₂✓

Or

Difficulty / uncertainty in lining up the (centre of the) spot with a graduation on the ruler ₂✓

Or

Difficulty / uncertainty in locating the position of A / B ₂✓

Do not allow:

- *because the smallest division is 1 mm*
- *hard to see measurements to less than 1 mm (need to link to position of spot (or A or B)*
- *“because of both sides of the ruler” on its own*
- *“ruler slightly misaligned” too vague*

the uncertainties from two (readings) are added ₃✓

insufficient includes:

- *uncertainty doubles*
- *uncertainty is twice the smallest division*
- *Random error or human error or error without further detail.*

However:

The uncertainty doubles because there are two readings scores MP1

Also:

The uncertainty doubles because there are two readings with identical uncertainties would score 2 marks.

Mention of range of repeated measurements $\div 2$ is not applicable in this case.

(b) (Adds the uncertainties =) 4 (mm) ₁✓

Or

Use of by substitution

(percentage uncertainty=) $\frac{\text{uncertainty}}{\text{value}} (\times 100) (\%)$ ₁✓

(% uncertainty =) 0.74 or 0.7 (c.a.o) ₂✓ (1 or 2 significant figures only)

1st mark

Expect to see:

(percentage uncertainty=) $\frac{4}{544} (\times 100) (\%)$

Maximum 1 mark for

Condone (in substitution):

- 2/289, 2/255, 2/272, 2/544, 4/289, 4/255, 4/272
- power of ten errors (POT errors)
- must be a recognisable uncertainty

Maximum 1 mark for

use of

(percentage uncertainty=) $\frac{\text{uncertainty}}{\text{mean (value)}} (\text{value})(\times 100) (\%)$

along with substitutions of

- 2/289, 2/255, 2/272, 2/544, 4/289, 4/255, 4/272, 4/544
- power of ten errors

condone for 1 mark

((2/289 + 2/255) × 100 =)

1.48% or 1.5%

2nd mark

Condone working leading to 2nd mark for:

Use of (percentage uncertainty=) $\frac{2}{272}$

Do not allow mean of two separate % uncertainties or incorrect formula quoted and used in workings

(c) MAX 2

The percentage uncertainty in c is smaller than for a or b because c has a larger value (than a or b separately)₁✓

or % uncertainty in c is half the percentage uncertainty in $a + b$ ₁✓

or The percentage uncertainty in c is smaller because its uncertainty is smaller for the same data value ₁✓

Insufficient:

- c has a smaller uncertainty
- $a + b$ has a larger uncertainty
- The uncertainty of $a + b$ is combined

c 's (% uncertainty =) 0.37 or 0.4 ₂✓ or c 's (% uncertainty =) $\frac{2}{544} \times 100$ ₂✓

idea that c 's measurement involves fewer readings than the sum of a and b ₃✓

or

idea that c requires fewer measurements than the sum of a and b ₃✓

Accept converse

Where numbers are quoted, these must be consistent with terms used.

4 readings, 2 readings

2 measurements, 1 measurement

2

(d) (when laser is switched on) always stand behind the laser (unless taking readings) ✓

Or

if in front of laser (when switched on) look away from the laser (eg when taking readings) ✓

Or

if in front of laser (when switched on) don't look at/towards the laser (eg when taking readings) ✓

Or

don't look directly into the laser (beam) ✓

Or

direct laser towards nearest wall ✓

Or

switch off laser when not in use ✓

Or

ensure (glass) reflective surfaces are covered (prevent reflections) ✓

Or

Do not shine the laser onto a reflective surface ✓

Or

place safety notices outside the laboratory [room] ✓

Or

don't shine laser at eye level ✓

Or

mark positions with pen/pencil and measure after laser switched off ✓

Or

laboratory is normally illuminated (not darkened) ✓

Where a list of safety measures has been given:

- *Treat more than one correct as neutral*
- *Penalise incorrect safety measure in a list that may include correct safety measures.*

Do not credit weak statements:

- *Do not look at the laser*
- *Don't point the laser anywhere except at the grating*
- *Don't look directly at the laser*

Beware of references to "the light".

1

(e) $(\tan \theta = \frac{0.544}{1.280} = \theta \Rightarrow) 23.0(^{\circ}) \checkmark$

allow 2 or more significant figure answer

acceptable common answers:

23, 23.0, 23.03, 23.025, 23.0255

Where more than 3 sf quoted, the number must be correct.

alternative method

(valid attempt to determine distance from grating to spot E, eg

(distance = $(\sqrt{0.544^2 + 1.280^2}) = 1.391$)

(sin $\theta = \frac{0.544}{1.391} = 0.391$)

($\theta \Rightarrow$) 23.0(^{\circ}) ✓

allow 2 or more significant figure answer

acceptable common answers:

23, 23.0, 23.03, 23.025, 23.0255

Condone mid-calculation rounding leading to errors in 4th sf where quoted.

1

(f) use of $n\lambda = d\sin\theta$ $_1\checkmark$

or

(if nothing else seen) $d = 3.3 \times 10^{-6}\text{m}$ $_1\checkmark$

Use of:

Correct rearrangement where subject would be λ

or correct substitution of n , d and θ

Expect to see $n = 2$, $d = 3.3(3) \times 10^{-6}$, $\theta = 23(.0)$

*Condone **one** error in substitution for n or d in a correctly rearranged equation where subject would be λ*

(or where answer indicates the correct working for incorrect numbers, d error leads to 5.86×10^4)

Condone power of ten errors in working

$\lambda = 6.5(2) \times 10^{-7} \text{ (m)}$ $_2\checkmark$ ecf

2 or 3 sf only

where 3 sf quoted answer must be in range 651 to 652 nm (or ecf)

Common ecf (sin θ error in 1.5):

Expect to see an answer that rounds to $7.1 \times 10^{-7}\text{m}$ to 2 sf

2

(g) The second mark ($_2\checkmark$) is contingent on the award of the first mark ($_1\checkmark$).

Increase distance from grating to screen / increase y $_1\checkmark$

(This will increase distance y (and/or c) therefore) decreasing the percentage uncertainty in y / c / fringe spacing / θ / $\sin \theta$ $_2\checkmark$

Do not accept:

- *darkened room*
- *use a (vernier) caliper*
- *use a travelling microscope*
- *Repeat*
- *Repeat and average*
- *Computer / data logger / camera*
- *Ruler with smaller divisions*
- *Make the maxima further apart (details on how this is achieved are required)*
- *Increase distance between laser and screen.*

Decreases the percentage uncertainty in y $_2\checkmark$

Or

Use a higher-order spot $_1$ ✓

(This will increase distance from centre spot to higher-order spot therefore) decreasing the percentage uncertainty in the fringe spacing/ θ /sin θ $_2$ ✓

Condone reference to this distance as c

Or

Measure distance between A and E $_1$ ✓

(This increases the distance therefore) decreasing the percentage uncertainty in c $_2$ ✓

No details of determination of c are required.

2

[12]

20.

C

[1]

21.

(a) Ray enters (prism) along normal ✓

Allow normal explained eg at right angles to surface

Accept "angle of incidence is 0".

1

(b) Treat each point independently.

Prism material/it has/they have same refractive index / optical density as windscreen ✓

Condone 'it has' or 'they have' or just 'same'

Allow "no change of speed between prism and windscreen"

Allow "made from same material"

Do not allow "same refractive index between them"

Treat "monochromatic" as neutral

Prism fitted to windscreen without gaps ✓

Allow "contact between prism and windscreen is clean" etc. Allow "touching the windscreen"

Condone suggestion that any bonding material has same refractive index (as prism and windscreen).

Do not accept 'no boundary'

2

(c) $C = \arcsin(1/1.52) = \arcsin(0.66) = 41(.1)^\circ \checkmark$

The first mark is for the calculation.

$45^\circ > \text{critical angle} / 41.1^\circ$ resulting in total internal reflection / tir (at each boundary)

$\checkmark$

The second is for the discussion but is contingent on obtaining a value for C.

Ecf for any $C < 45^\circ$

Accept clear reference to angle at point A in place of 45° statement.

Do not allow "angle of incidence > critical angle" on its own.

2

(d) Calculation of critical angle at glass–water boundary (61.0°)

OR

Calculation of possible n from glass to water (0.707) or absolute n for glass (1.88)

OR

Calculation of angle of refraction in water (53.9°) $\checkmark$

So total internal reflection no longer takes place

OR

some light escapes/refracts (into water) / less light reflects $\checkmark$

(Less light stays within windscreen so less light detected at sensor)

Do not allow suggestion that TIR occurs at critical angle/when angle of incidence=critical angle.

Do not allow "ray/all the light escapes/refracts" or "no light reflects" or "less TIR".

Do not condone "total internal refraction/diffraction"

2

- (e) Statement of effect of change in n on the path direction ✓

Eg for MP1

- *Light may change direction inside windscreen*
- *Light may change direction at a windscreen boundary*

(Sensible reference to the variation of a few per cent) leads to the idea that change is unlikely to be significant ✓

Eg for MP2

- *Variation too small to deviate significantly within windscreen – internal effect*
- *Variation too small to affect tir at A without droplet – boundary effect*
- *Variation too small to significantly affect transmission at A with droplet – boundary effect*

Allow discussions that may cause a difference, eg there is a summative effect from multiple reflections etc

MAX 2

- (f) **More sensitive because...**

more likely to encounter/detect water drop OR will encounter more water drops ✓
bigger decrease in light intensity, so more sensitive to rain ✓

Less sensitive because...

more likely to encounter imperfections in glass/on surface of glass /dirt on surface of glass ✓

any curvature effects will be greater so may not hit detector ✓

light intensity reduced without presence of water / greater absorption in windscreen due to greater path length ✓

Allow any 2 comments taken from list.

There must be a sense of whether the comment relates to an improvement or decrease in sensitivity.

Treat as list; mark 1 and 2 independently.

Allow idea of larger area

Do not allow a response that discusses travel time of ray.

MAX 2

[11]

22.

D

[1]

23.

- (a) Central maximum with lower intensity maxima (either side) ✓

MP1 is for comparison of intensity. Condone references to brightness/dimness.

Central maximum is twice as wide/wider than other maxima ✓

MP2 is for comparison of width

Award credit for a drawn answer eg on Fig 1.

Suggestion that pattern due to white light = max 1

Reference to Young's slit or equation = max 1

If only a single maximum is referred to MP2=0 but MP1 can score for description of intensity variation.

2

- (b) Wider (central) maxima (maximum) ✓

'The pattern is wider/more spread out' gets 1 mark if no other marks given.

Not "larger pattern".

(Subsequent) maxima further apart ✓

Condone "larger" distances between maxima.

Condone 'maxima more spaced out'

Reference to Young's slit or equation = max 1

Ignore comments related to change in wavelength

2

- (c) $d = 1 \times 10^{-3}/500 (= 2 \times 10^{-6})$ ✓

Allow POT error for d for MP1

$$(\sin \theta = n\lambda/d = 6.5 \times 10^{-7} / 2 \times 10^{-6} = 0.33)$$

$$\theta = 19^\circ \text{ ✓}$$

May be seen in diffraction grating equation.

Allow max 1 for use of grating constant rather than d to give

$7.45 \times 10^{-11}^\circ$ if no other credit available.

2

- (d) Any two from: ✓ ✓

(Range of wavelengths results in):

Central maximum unchanged in width

Broader maxima/range of angles for each maximum/order

Gradually getting broader/more spread out for greater order maxima

Part of third order maximum suppressed at long wavelengths (for $\theta > 90^\circ$)

Give credit for answer shown in diagram

Evidence for these marks may be seen in calculations

Treat intensity variation as neutral.

2

[8]

24.

- (a) TWO FROM:

central white fringe ✓

(fringes either side) showing range of colours/spectrum ✓

with red furthest and blue/violet closest to centre ✓

Allow rainbow for spectrum

Reject different colour fringes

If colours mentioned for last mark must be in right order i.e. red last

1

1

(MAX 2)

- (b) FOUR FROM:

central fringe is a mixture of red and green light/two wavelengths ✓

EITHER (1 marks)

(separate) red and green fringes are seen (on either side) ✓

OR (for 2 marks)

spacing of green fringes is less than spacing of red fringe / green fringes closer to middle than red ✓ ✓

OR (for 3 marks)

spacing of red fringes is 20% (or 1.2 times) greater than green fringes ✓ ✓ ✓

6th green fringe overlaps with 5th red fringe ✓

Allow orange/yellow for central fringe

If w used must be identified as fringe spacing for third alternative

1

1

1

1

(MAX 4)

- (c) The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria	QoWC
6	Explains how (%) uncertainties combine to determine uncertainty in wavelength OR identify % uncertainty s as being the largest	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear.
5	Explain how wavelength is determined using $\lambda = \frac{ws}{D}$	The text is legible.
4	Explains how second change affects fringe spacing AND Comments on how change in fringe spacing affects (%)uncertainty / change in s OR D affects (%)uncertainty	The student presents relevant information and in a way which assists communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.
3	Explains how second change affects fringe spacing OR Comments on how change in fringe spacing affects (%)uncertainty / change in s OR D affects (%)uncertainty	
2	States how one of the changes affects fringe separation (decrease s increases fringe separation / decrease D decrease fringe separation)	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.
1	States that one of the changes alters fringe separation	
0	No correct change identified	The student's presentation, spelling and grammar seriously obstruct understanding.

The following statements may be present for decreasing slit separation s:

Fringe separation increases

Uncertainty in measuring fringe separation will decrease

and as this is needed to measure wavelength,

uncertainty in wavelength

measurement will decrease

The following statements may be present for smaller D:

Uncertainty in measuring D would increase

Fringe separation would also decrease

so uncertainty in measuring fringe separation would increase

Both are required to find wavelength so uncertainty in finding wavelength would increase

*FOR Middle Band **one** of these considered:*

Decrease s

Larger fringe separation so smaller (%) uncertainty (in w)

Smaller s so higher (%) uncertainty in s

Decrease D

Smaller fringe separation so larger (%) uncertainty (in w)

Smaller D so higher (%) uncertainty in D

If explain reverse change correctly (s increase D increase) no penalty

6

[12]

25. D

[1]

26. A

[1]

27. (a) Use of $n_A = \frac{c}{c_A}$ to make c_A the subject of the equation

Condone truncation without appropriate rounding mid-calculation

OR

speed in glass **A** = $2.05(2) \times 10^8 \text{ ms}^{-1}$ ₁✓

Speed in glass **B** = $1.985(3) \times 10^8$

Condone use of $c = 3 \times 10^8$

But must see answer to 4 sf answer

OR

their speed in glass **A** $\times 0.96748$ (or equivalent) ₂✓

Values obtained using $c = 3 \times 10^8$:

- *speed in glass A = $2.05(3) \times 10^8 \text{ ms}^{-1}$*
- *speed in glass B = $1.98(7) \times 10^8$*
- *$n = 1.510$*

OR

Alternative 1st and 2nd marks

Use of $n_A/n_B = c_B/c_A$ by substitution for n_A ₁✓

Use of $n_A/n_B = c_B/c_A$ by substitution for n_A and $c_B = c_A \times 0.96748$ ₂✓

OR

$n_B = 1.461 / 0.96748$ ₁✓₂✓

Watch for maths errors:

Dividing by 1.03252 $\neq$ multiplying by 0.96748

Multiplying by 1.03252 $\neq$ dividing by 0.96748

1.510 cao to 4 sf only ₃✓

Correct answer to 4 sf obtains all 3 marks

Penalise any unit on final answer

3

(b) **Relationship:**

Increase in tension (or stress) in cable produces increase in strain resulting in increase in

λ_R

OR

Decrease in tension (or stress) causes decrease in strain resulting in decrease in λ_R 1✓

Variation due to motion:

As the lift accelerates downwards, (the tension is less than the weight in the cable, a decrease in tension results) in λ_R decreasing 2✓

At constant velocity (the tension again equals the weight and) λ_R returns to the initial, at rest value 3✓

Allow a correct comment on the directional relationship between tension, strain and λ_R independent of the motion of the lift for first mark

3

- (c) **P** because it will produce a larger increase in λ_R for the (same) increase in strain

OR

P because it has a larger gradient (must be a sense of larger increase in λ_R for the (same) increase in strain) ✓

Hence smaller accelerations (which produce small changes in strain) can produce measurable changes in λ_R

OR

Hence gauge **P** will have a higher resolution ✓

Selecting Q gains zero marks

Linking steeper gradient to being able to withstand a larger force negates this mark

Allow more accurate measurement of acceleration

Allow more readings of acceleration can be taken (over the range)

More sensitive treat as neutral

2

[8]

28.

C

[1]

29.

C

[1]

30.

D

[1]

31.

B

[1]

32.

C

[1]

33.

(a) $i = \sin^{-1} (1/1.6) = 39^\circ \checkmark$

1

(b) $\sin 58 = n/1.6 \checkmark$
 $n = 1.4 \text{ (1.36)} \checkmark$

1

1

- (c) blue light undergoes TIR $\checkmark$
 red light refracted $\checkmark$
 reason i.e. critical angle for red light is more OR critical angle for blue light is less $\checkmark$

Allow correct description of refraction. Ignore statements about towards/away from normal

OR

- if refractive indices change by same factor $\checkmark$
 critical angle stays constant $\checkmark$
 so path followed by red and blue light is the same $\checkmark$

OR

- don't know if refractive indices change by same factor $\checkmark$
 so can't predict the effect on critical angle $\checkmark$
 so can't predict paths of red and blue light $\checkmark$

For second two alternatives third mark (i.e. about paths of red and blue) dependent on first mark (i.e. factor of refractive index change)

1

1

1

[6]

34.

A

[1]