# MARK SCHEME

PHYSICS

AS-Level

PROPERTIES OF WAVES

TEST 2

# Mark schemes

**1** (a) 2.9% ✓

*Allow 3%*

1

(b) $\frac{1}{3.5 \times 10^3}$ seen ✓

1

0.29 mm or 2.9 x $10^{-4}$ m✓ must see 2 sf **only**

1

(c) ± 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*
*Allow answer within range ±0.05*

1

(e) Substitution in $d \sin\theta = n\lambda$✓

*The 25 spaces could appear here as n with sin θ as 0.135 / 2.5*

1

$d$ = 0.300 x $10^{-3}$ m so
number of lines = 3.34 x$10^3$✓

*Condone error in powers of 10 in substitution*

*Allow ecf from 1-4 value of spacing*

1

(f) Calculates % difference (4.6%) ✓

1

**and** makes judgement concerning agreement ✓

*Allow ecf from 1-5 value*

1

(g) care not to look directly into the laser beam✓
**OR**
care to avoid possibility of reflected laser beam ✓
**OR**
warning signs that laser is in use outside the laboratory✓
**ANY ONE**

1

**[10]**

**2** (a) A wave transfers energy <u>from one point to another</u> ✓
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 $s^{-1}$) ✓ (1.82 m $s^{-1}$)

*allow CE v = (biii) × (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 <u>in</u>crease or <u>de</u>crease clearly distinct.*

*Marking should be lenient.* **3**

**[10]**

**3** (a) Answer D ✓ (violet) **1**

(b) (light from each slit) <u>superpose</u>
light from adjacent slits have a path difference of <u>one</u> wavelength
(at this angle all) the waves are in phase
constructive interference / peaks coincide / (positively) reinforce

any 3 points ✓ ✓ ✓ max 3

*Ignore reference to nodes or antinodes*

*If general statements are made only give marks for parts related to 'Bright line' or 'First order' which appears in the question.* **3**

(c) (i) use of sin $\theta = \lambda / d = 5.3 \times 10^{-7} / 1.8 \times 10^{-6}$ ✓ (= 0.294)

$\theta = 17°$ ✓ (17.1°)

*Answer alone scores both marks*

**2**

(ii) ( use of $n = d \sin \theta / \lambda$) $n_{max} = (d \sin 90° / \lambda) = d / \lambda =$ ✓

$= 1.8 \times 10^{-6} / 5.3 \times 10^{-7} = 3.4$ ✓

max order = 3 ✓

*Showing that n=4 is not possible is not answering the question but the first mark (equation mark) can be gained this way*

*Max order is an independent mark from reducing a calculated value for n to the next lowest integer.*

**3**

**[9]**

**4** (a) (i) sin$C = 1/n = 1/2.42$ ✓ (= 0.413)

$C = 24.4°$ ✓ (allow 2 or more sig figs)

*Answer only gains both marks*

**2**

(ii) $\sin \theta_{dia} = \sin \theta_{air} / n = \sin 50.2 / 2.42$ ✓ (= 0.317)

$\theta_{dia} = 18.5°$ ✓ (allow 2 or more sig figs)

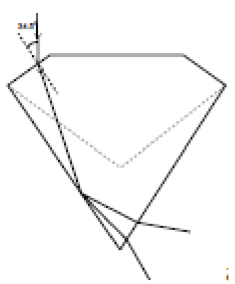
*Answer only gains both marks*

*Answer can be 18° or 19° depending on rounding*

**2**

(iii) TIR shown at bottom left surface ✓(If the reflected ray were extended it would pass through the writing below the diagram between the 'i' in 'it' and the full stop at the end of 'diamond'.) ray leaves bottom right surface either with an increased emergent angle or straight though if hitting normally ✓

(The second mark is consequential on gaining the first mark)



*acceptable emergent rays*

**2**

(iv) it has smaller critical angle / critical angle is 22°

allowing more / same number / greater chance / increased probability of TIR's occurring

greater/same sparkle ✓✓ max 2

*'reflect more' is insufficient for a mark*

**2**

(b) (i) $c_{core} = c_{air} / n = 3.00 \times 10^8 / 1.55 = 1.9 \times 10^8$ ($ms^{-1}$)✓($1.94\times 10^8$ $ms^{-1}$)

*1 sig fig is not acceptable if no other answer is given*

**1**

(ii) ($n = c_{air} / c_{core} = f\lambda air / f\lambda core = \lambda air / \lambda core$ )

$\lambda core = \lambda air / n$ or $1300 \times (10^{-9}) / 1.55$✓

$= 8.4 \times 10^{-7}$ (m)✓($8.39 \times 10^{-7}$ m or 839 nm)

*The first mark is for the equation or substitution ignoring powers of 10 errors*

*1st mark can be gained from calculating the frequency ( $f = 3.0 \times 10^8 / 1300 \times 10^{-9} = 2.3 \times 10^{14}$ (Hz) which then can be used to find the the wavelength*

*Using this method the answer can range between $8.4 \times 10^{-7} \longrightarrow 8.7 \times 10^{-7}$ (m) and consider ecf's from (b)(i)*

**2**

(iii) protects the core (from scratches etc)

prevents crosstalk / stops signal crossing from one fibre to another / increases critical angle / reduces pulse broadening / reduces smearing / prevents multipath dispersion

allows fibre to be supported / touched (without losing light)

✓any one point

*Preventing signal loss is not enough for the mark.*

**1**

**[12]**

**5** (a) (i) Number of complete waves passing a point **in one second** / number of complete waves produced by a source **in one second** / number of complete vibrations (oscillations) **per second** / number of compressions passing a fixed point **per second**

**1**

(ii) 180° phase difference corresponds to ½ λ

Use of $v = f\lambda$ with correct powers of 10

0.33 (m)

**3**

(b) (i) Do not have the same frequency

do not have a constant phase difference

**2**

(ii) Waves meet antiphase

Undergo superposition

Resulting in destructive interference

**3**

(iii) $T$ = 100 ms

Use of $T = 1 / f$ or beat frequency ($\Delta f$) = 10 Hz

500 (Hz) (allow 510 –their beat frequency)

**3**

(c) (i) Only box ticked: Quality

**1**

(ii) Add regular alternating voltages together
With appropriate amplitudes
Where frequencies of voltages match the harmonics of sound / where frequencies are multiples of 440 Hz

*Allow 2 for sampling sound (at twice max frequency ) B1*

*Convert to binary ( and replay through D to A converter). B1*

**3**

**[16]**

**6** (a)

| | **wavelength** | **frequency** | **speed** |
|---|---|---|---|
| **increases** | | | |
| **stays the same** | | ✓ | |
| **decreases** | ✓ | | ✓ |

middle column correct ✓
first and third column correct ✓

**2**

(b) (i) ($n_1 \sin\theta_2 = n_2 \sin\theta_2$)
(1.09)sin 65.0 = (1.00)sin$\theta_2$ ✓ (giving $\theta_2$ = 81°)

α = 9(°) ✓ (8.93°)

*no internal CE*

*allow 9.0°*

**2**

(ii) 1.09sin65 = 1.70sin$x$
or sin$x$ = 0.58
or $x$ = 35.5 (°) ✓ (allow 35° or 36°)

*[beware an answer close to the correct value can come from*

*n = 1 / sinC]*

90 − 35.5 = 54.5(°) ✓ (allow 54° or 55°)
CE for 90° − their value

**2**

(c) (i) <u>total</u> internal reflection

*TIR does not gain the mark*

**1**

(ii) diagram showing core / cladding and light ray TIR at interface at least once with another TIR shown on the diagram or suggested in their explanation ✓

*labelling is not required and reflections do not have to be accurate provided they are shown on the correct side of the normal*

light fibre consists of core and cladding with lower refractive index / optical density ✓

light (incident) at angle greater than the critical angle (results in TIR) ✓

**3**

**[10]**

**7** (a) Core is transmission medium for em waves to progress (by total internal reflection) ✓

*Allow credit for points scored on a clear labelled diagram.*

**1**

Cladding provides lower refractive index so that total internal reflection takes place ✓

**1**

And offers protection of boundary from scratching which could lead to light leaving the core. ✓

**1**

(b) Blue travels slower than red due to the greater refractive index

Red reaches end before blue, leading to material pulse broadening ✓

*The first mark is for discussion of refractive index or for calculation of time difference.*

**1**

Alternative calculations for first mark

Time for blue = $d / v = d / (c / n)$ = 1200 / (3 × $10^8$ / 1.467) = 5.87 × $10^{-6}$ s

Time for red = $d / v = d / (c / n)$ = 1200 / (3 × $10^8$ / 1.459) = 5.84 × $10^{-6}$ s

Time difference = 5.87 × $10^{-6}$ – 5.84 × $10^{-6}$ = 3(.2) × $10^{-8}$ s ✓

*The second mark is for the link to material pulse broadening*

**1**

(c) Discussions to include:

Use of monochromatic source so speed of pulse constant

Use of shorter repeaters so that the pulse is reformed before significant pulse broadening has taken place.

Use of monomode fibre to reduce multipath dispersion ✓ ✓

*Answer must make clear that candidate understands the distinction between modal and material broadening.*

**2**

**[7]**

**8** (a) (i) sin 60 = 1.47sin θ **OR** sin θ = sin 60 / 1.47 ✓

($\sin^{-1}$ 0.5891) = 36 (°) ✓ (36.0955°) (allow 36.2)

*Allow 36.0*

2

(ii) <u>sin $\theta_c$ = 1.33 / 1.47</u> OR <u>sin $\theta_c$ = 0.9(048)</u> ✓

($\sin^{-1}$ 0.9048) = 65 (°) ✓ (64.79)

*Allow 64 for use of 0.9 and 66 for use of 0.91*

2

(iii) answer consistent with previous answers, e.g.
if aii >ai:
ray refracts at the boundary AND goes to the right of the normal ✓
Angle of refraction > angle of incidence ✓ **this mark depends on the first**

if aii < ai:
TIR ✓
angle of reflection = angle of incidence ✓

ignore the path of the ray beyond water / glass boundary

*Approx. equal angles (continuation of the line must touch 'Figure 1' label)*

2

(b) for Reason or Explanation:
the angle of refraction should be > angle of incidence when <u>entering the water</u> ✓
water has a lower refractive index than glass \ light is faster in water than in glass ✓

TIR could not happen \ there is no critical angle, when ray travels from water to oil ✓
TIR only occurs when ray travels from higher to lower refractive index \ water has a lower refractive index than oil ✓

*Allow 'ray doesn't bend towards normal' (at glass / water)*

*Allow <u>optical</u> density*

*Boundary in question must be clearly implied*

4

**[10]**

**9** (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 <u>named source</u> 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', 1st*

**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 / (lines per mm × $10^3$)
= $6.757 \times 10^{-7}$ (m) OR $6.757 \times 10^{-4}$ (mm) ✓

( $n\lambda = d \sin\theta$ )
= $6.757 \times 10^{-7} \times \sin 51.0$ ✓ 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

= $5.25 \times 10^{-7}$ (m) ✓ 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 =*

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

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

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

**3**

(d) n = d (sin90) / λ   OR n = 6.757 × $10^{-7}$ / 5.25 × $10^{-7}$ ✓ ecf both numbers from c

= 1.29 so no more beams observed ✓ or answer consistent with their working

**OR**

2 = d (sinθ) / λ OR sinθ = 2 × 5.25 × $10^{-7}$ / 6.757 × $10^{-7}$ ✓ ecf both numbers from c

sinθ = 1.55 (so not possible to calculate angle) so no more beams ✓

**OR** $\sin^{-1}$(2 × (their λ / 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]**

**10** (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 + / − 2 squares.*
*Minima on the x axis + / − 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]**

## Examiner reports

**2** (a) For a majority this was a piece of work that was never committed to memory and the marks were low. Only about half the students scored the mark about the wave being able to transport energy from one place to another. Then only a small subgroup of these students referred to matter not being transported.

(b) (i) Almost all students found this basic question straightforward.

(ii) Almost all students found this basic question straightforward.

(iii) Again the vast majority of students had no problems but a few got into difficulty in reading the time scale correctly.

(iv) The equation for velocity was known by almost all the students and most scored the mark.

(c) A majority of students chose the correct responses but there was a significant number tempted away by one or more of the distractors.

(d) This question discriminated between students very effectively. Many did appreciate that a higher frequency meant a shorter wavelength. This in turn had the effect of compressing the diffraction pattern. Students had some difficulty in expressing this idea. Instead of simply saying the central peak was narrower they might say the wave is shorter. Only the very able students obtained a third mark. Most said the pattern shown would have the same height because the amplitude was the same.

**3** (a) Although the correct answer (violet) was the most common response all the alternatives were given in significant numbers.

(b) On the whole the answers were set out well. A majority of students discussed constructive interference as well as superposition. Inevitably some wrote 'superposition as 'superimposition'. It was also common to see an 'in-phase' statement but only a minority made all three statements. The idea that the path difference between light coming from adjacent slits was one wavelength was not seen often. The path difference was normally given as n times the wavelength. Students also failed to gain marks by describing the whole pattern of light and dark fringes in which it was not clear what part of the pattern a reference to 'constructive interference' belonged.

(c) (i) This calculation was performed well and the usual tail of students who have difficulty in using a calculator was not seen.

(ii) Most students performed this calculation as shown in the mark scheme. Other students who chose to show the diffraction angle of each order including the fourth order, which is not possible, could score full marks. However many of those students did not show enough work to justify their answer. For example, showing only that the fourth order is not possible does not exclude the answer 'second order'.

**4** (a) Both the geometric optics calculations in parts (i) and (ii) were done very well by students.

(iii) This question gave a good spread of marks. Although a majority scored well, errors were seen at each stage. The most common error was to simply copy what happened in the figure, which resulted in an incorrect angle of reflection on the first surface. In other cases the reflections were drawn from the dotted lines in the figure. The other common mistake was for the TIR on the first surface to be drawn with the angle of reflection not looking close to the angle of incidence.

(iv) This question was very discriminating. More able students knew exactly what they were doing but many others either simply suggested it would reflect more or less and gave the reason as the refractive index was higher. Even when they related the refractive index to the critical angle they often related this to the conclusion in the wrong way. For example they may have said 'lower critical angle so the rays of light are less likely to be reflected.

(b) (i) This straightforward calculation was done well by a majority.

(ii) This was again done well but it gave rise to a few more errors compared to the previous part.

(iii) There was a huge number of correct possible answers for using cladding and a majority of students chose one of them. However a significant number of students thought that the cladding made TIR more likely or prevented light escaping from the core.

**5** (a) (i) Acceptable definitions were given by a good majority of the students. Those who failed to produce a satisfactory response usually omitted reference to time.

(ii) Most gained credit for the use of $v = f\lambda$ . The common errors were ignoring the k in kHz and not calculating $\lambda/2$.

(b) (i) This question was a ‘twist’ on a commonly asked question that requires students to explain what is meant by waves being coherent. This question required students to identify that the tuning forks had different frequencies and would not have a constant phase difference when they arrive at a point so would not be coherent. This proved to be too challenging for many students.

(ii) This was poorly done and fewer than half the students were able to give at least one acceptable point worthy of credit and there were relatively few who gained full credit. One can only speculate that students have difficulty understanding interference that occurs due to changes in phase difference that take place at a point with time as is the case in this instance.

(iii) A high proportion of the students gained credit for use of $f = 1/T$ and many of these arrived at the correct beat frequency. Many did no more than this and relatively few of these went on to calculate the correct frequency of the fork that emitted the lower frequency.

(c) (i) Almost three quarters of the students selected the correct response to this question.

(ii) Relatively few appreciated the meaning of synthesis of sound ie the process of adding together sinusoidal waves of appropriate frequencies and amplitude to produce a required sound. Students were given compensatory credit for explaining the process of sampling a sound and storing it digitally.

**6** This question showed up a lack of geometrical knowledge in some students but strong students sailed through. In (b)(i) most students knew Snell’s Law as applied to the boundary between two media. Unfortunately, many did not choose to use the correct refractive indices or use the correct angles. The use of 25° in place of the correct 65° featured prominently. The students who had problems with (b)(i) also had problems in (b)(ii). There was the potential for an error carried forward mark for students who presented a value for the angle *x* as in the mark scheme. However, only a minority of these students correctly found the answer to this section by subtracting *x* from 90°.

Although (c)(ii) asks for a diagram, weaker students sometimes chose not to give one or when they did it showed an optical fibre without cladding. In this way they failed to gain the first mark. The other two marks were only obtained by stronger students. More students chose to give an answer that involved the critical angle than an answer involving the refractive indices. Only the strongest students scored all three marks.

**8** (a) (i) Most candidates produced excellent answers, but there were a few slips, especially with use of 1.33 rather than 1.47.

(ii) Most candidates gained 2 marks here but a few did not use the refractive index of water (1.33) for $n_2$. It is perhaps the case that some students believe that $n_2$ is always 1 when calculating the critical angle.

(iii) A common mistake seen here was the use of the phrase 'Total internal refraction' rather than 'Total internal reflection'.

It was also extremely common for candidates to say that light would not TIR because it 'hadn't reached the critical angle' for the water-oil boundary. There would be no TIR (and thus no critical angle) because the light is travelling from a lower to a higher refractive index material and under these conditions, the light will refract and there will only be a partial reflection.

(b) In this question candidates sometimes showed TIR despite having successfully calculated the angle of incidence and the critical angle. Candidates received full credit if their answer was consistent with their previous two answers but this was not seen very often. Of those who chose refraction, some unfortunately had the ray bending towards the normal or even, in a few cases, refracting to the left of the normal line.

**9** (a) There were some rather vague answers here such as '*To calculate the wavelength of a light*' or '*to look at the light from stars*'. There needed to be a little more than this to get the mark, i.e. a specific example such as 'analyse the elements present in the atmosphere of a star' or explain that the composition of a material or gas can be determined.

(b) The candidates who knew this often lacked detail in their answer, e.g. 'it would be dimmer'. Some thought there would only be one colour at **B** rather than a spectrum.

Quite a few thought that the wavelength at **B** would be different from **A** due to the increased angle.

Some candidates thought that the light at **B** would be composed of different wavelengths and the white light at **A** would be a single wavelength.

(c) This was a fairly standard exam question but surprisingly there were few correct answers. Students seemed to be poorly prepared for this question and confusion reigned regarding the meaning of the terms in the grating equation. Use of the *lines per mm* as the line spacing ($d$ = 1480) was very common.

There was also confusion between line spacing, $d$, and order, $n$. Some used 1480 for $d$ and for $n$.

Candidates often used 1 / 1480 and then failed to convert this into metres.

(d) There were a surprising number of candidates who did not attempt this question. Even if they felt they had the wrong numbers for wavelength and line spacing in part (c), candidates simply needed to divide their $d$ by their $\lambda$, and if greater than 1, conclude that no further orders are possible.

There was also some confusion over the method required, e.g. some used the angle given in part (c), (51°), and calculated a new wavelength that would give a second order at that angle.

**10** (a) In general, this was a well answered question apart from a tendency for candidates to add extra detail, e.g. *'single wavelength <u>and coherent</u>'*; this loses the mark. As does: *'single wavelength / colour'*; because this implies that monochromatic could be just a single colour. However, *'light of a single wavelength and therefore a single colour'* would be acceptable. It is therefore best to learn the appropriate definition and not add any further detail.

(b) Many candidates did not know what to do on this question.

The red light subsidiary maxima were often shown closer to the central maximum than the blue.

Perhaps single slit diffraction tends to be a little overlooked because the specification does not require any mathematical description. Nevertheless, students should be shown images of the single slit pattern and how it changes for different wavelengths. Images are readily available on the internet via any search engine.

(c) When talking about laser safety, it is not acceptable to say simply 'wear *goggles'*. One must say *'<u>laser</u> safety goggles'*, *'<u>laser</u> safety glasses'*, or *'<u>laser</u> safety eyewear'*. Standard laboratory goggles would not afford any significant protection against laser light.

(d) Only a few candidates were able to describe the pattern accurately. Answers tended to be vague and ambiguous. Only a small number decided to add a sketch to clarify their answer and this approach should be encouraged. Again, perhaps the single slit has been overlooked by some in favour of the 'more difficult' double slit and grating.