Mark schemes

1 A **[1]**

2 C **[1]**

3 B **[1]**

4 A **[1]**

5 B **[1]**

6 B **[1]**

7 C **[1]**

8 D **[1]**

9 (a) $w = \lambda D/s$ C1

correct substitution – condone wrong powers of ten C1

cao 11(.3) mm or equivalent; **unit required** A1

3

(b) same frequency or wavelength C1

constant phase (relationship) A1

2

[5]

10 (a) $\lambda = yd/D$

C1

substitution correct: $\frac{7.8 \times 10^{-3} \times 2.5 \times 10^{-4}}{3.5}$ condone powers of 10

C1

5.6×10^{7} m

A1

3

(b) waves arrive out of phase (with each other)

B1

path difference is 1.5λ

B1

idea of cancellation/destructive interference/negative interference destruction

B1

3

[6]

11 (a) constant phase relationship **(1)** **(1)**
[or same frequency (wavelength) **(1)** and same phase difference **(1)**]

2

(b) S_1R = 15cm on diagram **(1)** =75cm ∴ 30 waves **(1)**
S_2R = 16cm on diagram (1) = 80cm ∴ 32 waves **(1)**
2 whole waves difference so in phase at R **(1)** maximum **(1)**

max 5

(c) (falls then rises to) maximum at Q **(1)**
(then falls and rises to) maximum at P **(1)**

2

(d) $f\left(=\frac{c}{\lambda}\right) = \frac{3.0 \times 10^{8}}{25 \times 10^{-3}}$ = 1.2×10^{10} Hz (or 12 GHz) **(1)**

1

[10]

12 (a) (i) superposition **(1)**
between waves in phase **(1)**
gives constructive interference **(1)**

(ii) at D or E waves out of phase **(1)**
so destructive interference **(1)**

max 4

(b) (i) $\lambda = \frac{330}{2 \times 10^3} = 0.165$m **(1)**

separation between maxima = $\frac{\lambda D}{s}$ **(1)**

$\left(= \frac{0.165 \times 5}{0.75}\right) = 1.10$(m) **(1)**

distance CE (= $\frac{1}{2}$ × separation)= 0.55 m **(1)**

4

[8]

13 (a) Constant/zero phase difference/in phase

B1

same frequency/wavelength

B1

2

(b) (i) mention of interference C1

describes constructive interference **OR** destructive interference **OR** discusses path difference

A1

(ii) [λ*D*/*d*]

0.77*65/8.5

C1

=5.9 [5.89] m

A1

4

[6]

14 (a) (i) Because the bright fringes and dark fringes **(1)** produced by double slit interference **(1)**

(ii) $w = \frac{\lambda D}{s} = \frac{630 \times 10^{-9} \times 5.0}{0.25 \times 10^{-3}}$ **(1)** = 12.6 (13) mm **(1)**

(iii) from graph, time to travel between adjacent bright fringes = 0.25 s **(1)**

use w = 13 mm and $\upsilon = \frac{w}{t}$ **(1)**

to give $\upsilon = \frac{13 \times 10^{-3}}{0.25}$ = 52 mm s^{-1} or 5.2×10^{-2} m s^{-1} **(1)**

(max 5)

(b) V_2 = value corresp to low resist ∴ bright fringe **(1)**

$= 6 \times \frac{5}{15} = 2.0$ V **(1)**

$V_2 = 6 \times \frac{5}{10} = 0.29$ V **(1)**

(3)

(c) e.g. use spring between glider & track end **(1)**
compress to same length each time, release **(1)**

(2)

[10]

15 (a) (i) **diffraction (1)**

(ii) **any 4 points from**

interference (fringes formed) **(1)**

where light from the two slits overlaps (or superposes) **(1)**

bright (or red) fringes are formed where light (from the two slits) reinforces (or interfere constructively/crest meets crest) **(1)**

dark fringes are formed where light (from the two slits) cancels (or interferes destructively/trough meets crest) **(1)**

the light (from the two slits) is coherent **(1)**

either
reinforcement occurs where light waves are in phase
(or path difference = whole number of wavelengths) **(1)**

or
cancellation occurs where light waves are out of phase of 180°
(in anti-phase)
(or path difference = whole number + 0.5 wavelengths) **(1)**
(not ‘out of phase’)

(iii) $\left(w = \frac{\lambda D}{s}\right)$ gives $\lambda = \frac{ws}{D}$ **(1)**

w (= 3.6/**4**) = 0.9(0) mm **(1)** (failure to /4 is max 2)

$\lambda \left(= \frac{ws}{D}\right) = \frac{0.90 \times (10^{-3}) \times 0.56 \times (10^{-3})}{0.80}$ **(1)** = 6.3×10^{-7} m **(1)**

9

(b) central (bright) fringe would be white **(1)**

side fringes are (continuous) spectra **(1)**

(dark) fringes would be closer together (because λ_{red} > average λ_{white}) **(1)**

the bright fringes would be blue on the side nearest the centre
(or red on the side away from the centre) **(1)**

bright fringes merge away from centre **(1)**

bright fringes wider (or dark fringes narrower) **(1)**

max 3

[12]

16 (a) (i) fringe spacing = 0.11 m

B1

1

(ii) λ = (*fringe spacing from a*(i)) **d/D* [ecf] = 0.11 × 0.2/2.5

M1

= 8.8×10^{-3} m

A1

2

(b) **three maximum from**

mention of single-slit difraction *after*
good diagram of diffraction intensity
mention of interference fringes/two-slit *before*
interference/superposition/Young's slits or alternative *before*
good physics description of superposition
e.g. interference between overlapping waves from each slit
good physics description of diffraction
equally separated fringes *before*
central maximum is twice width of others *after*
decrease in intensity for each successive maxima *after*
change in spacing *after*
fainter from middle outwards *after*

B3 **3** **[6]**

17 (a) $\lambda D / d$ in symbols or numbers **C1**

$1.1 \times 10\ m^{-2}$ **A1** **(2)**

(b) same frequency / wavelength. **B1**

constant phase difference **B1** **(2)**

(c) Reference to out of phase **C1**

phase difference is 180° or π / path difference is $\lambda 2$ / explanation of **C1**

antiphase eg crest meets trough **A1**

destructive interference / description of cancelling out **B1** **(3)** **[7]**

18 (a) same wavelength or frequency **(1)**
(same phase or) constant phase difference **(1)** **2**

(b) (i) narrow slit gives wide diffraction **(1)**
(to ensure that) both S_1 and S_2 are illuminated **(1)**

(ii) slit S acts as a point source **(1)**
S_1 and S_2 are illuminated from same source giving monochromatic/same λ **(1)**
paths to S_1 and S_2 are of constant length giving constant phase difference **(1)**
[or $SS_1 = SS_2$ so waves are in phase]

Max 4
QWC 1

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

2

[8]

19 (a) (i) fringes formed when light from the two slits overlap (or diffracts) **(1)**
slits emit waves with a constant phase difference (or coherent) **(1)**
bright fringe formed where waves reinforce **(1)**
dark fringe formed where waves cancel **(1)**
[or if 3rd and 4th not scored, waves interfere **(1)**]
path difference from slits to fringe =
whole number of wavelengths for a bright fringe **(1)**
whole number + half a wavelength for a dark fringe **(1)**
[or phase difference is zero (in phase) for a bright fringe **(1)**
and 180° for a dark fringe **(1)**]

(ii) (interference) fringes disappear **(1)**
single slit diffraction pattern observed
[or single slit interference observed] **(1)**
central fringe (of single slit pattern) **(1)**
side fringes narrower than central fringe **(1)**

max 8

(b) (i) fringes closer **(1)**
(because) each fringe must be closer to the centre for the same path difference
[or correct use of formula as explanation] **(1)**

(ii) $\sin\theta_c \left(= \frac{n_2}{n_1}\right) = \frac{1.32}{1.50}$ **(1)** (= 0.88)

$\theta_c = 61.6°$ **(1)**

(iii) for second light ray, diagram to show:
smaller angle of incidence at P than first ray **(1)**
point of incidence at core / cladding boundary to right of first ray **(1)**
total internal reflection drawn correctly or indicated at point of incidence to right of right angle **(1)**

[alternative if ray enters at P from above:
correct refraction at P **(1)**
TIR at boundary if refraction at P is correct **(1)**
angle of incidence visibly ≥ critical angle **(1)**]

7

[15]

20 (a) (i) path difference clearly indicated correctly

B1

(1)

(ii) path difference must be $(n + ½)\lambda$ **not** just $½\lambda$
(accept odd number of wavelengths) (allow diagram)

waves arrive at **P** antiphase / totally out of phase / exactly out of phase / out of phase by by π **or** 180° (allow diagram)

B1

interfere destructively / cancel / "crests and troughs" at same time

B1

(3)

(iii) idea of waves spreading out at a slit / slits (allow diagram for this mark)

B1

production of overlapping beams from the double slit or illuminating both slits in double slit

B1

(2)

(b) fringe spacing = $\lambda D / d$
or correct substitution of data

C1

0.83 mm

A1

(2)

(c) (i) momentum of electrons = 1.27×10^{-24} (kg m s^{-1})
or $m \times v$ and correct substitution

C1

wavelength = h / p

C1

5.2×10^{-10} m

A1

or wavelength = h / p and $p = mv$; **or** h / mv

C1

correct substitution of data

C1

correct answer

A1

(3)

(ii) calculation of fringe spacing (= 7.8×10^{-7} m)
allow e.c.f. for d / D confusion in (b)

or ratio λ / d for each

B1

the fringe spacing is too small (to enable separate fringes to be seen)

B1

or calculation of D **or** of λ / d **or** speed for $\lambda \approx d$

B1

speed in apparatus much larger than
that needed to make $\lambda \approx d$

B1

(2)

[13]

21 (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 (Δf) = 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]

Examiner reports

9 In part (a), most candidates selected the correct equation for the double slit but there was often confusion between the slit separation and the slit-screen separation. A sizeable number of candidates had trouble with calculating the fringe separation to the correct power of 10 and single figure answers and lack of units (each of which was penalised) were not uncommon.

Few candidates knew the definition for coherence in part (b); most interpreted the question as asking for the conditions for a clear interference pattern and so equal or nearly equal amplitudes were frequently mentioned. Many candidates simply expressed the need for constant frequencies, wavelengths, phase, amplitude and velocity. The idea of a *constant phase relationship* was not generally understood with many candidates incorrectly equating constant phase with constant phase relationship.

10 (a) This calculation was done well by nearly all candidates. Only a few had difficulty and this was usually with powers often.

(b) Most of the candidates were able to make an acceptable comment about destructive interference and mention of the waves being out of phase was usual. Very few candidates stated that the path difference at the point in question was one and a half wavelengths. In fact, comments about path difference were relatively rare.

11 In part (a) the phrases "constant phase relationship" or "constant phase difference" were not as well known as they should have been. The majority of candidates were imprecise in their use of language.

A small number of candidates were handicapped in part (b) by the fact that they did not appear to have a ruler available to them. In general, parts (b)(i) and (b)(ii) of the question were done very well by the large majority of candidates. Those candidates getting parts (b)(i) and (b)(ii) wrong could score on part (b)(iii) if their argument was sensible.

Candidates made a sensible attempt at part (c), but many fell into the unintended trap and stated that Q corresponded to a minimum.

Far too many candidates made arithmetical errors in the straightforward calculation in part (d).

12 Most candidates answered parts (a) and (b) well. Many candidates showed correctly in part (b) that w = 1.1 m but failed to halve it to obtain CE. Too many candidates did part (b)(ii) by inspecting the diagram, ignoring the "not to scale", and incorrectly halving the 0.75 m to obtain what they thought looked like CE.

13 (a) Candidates were usually able to explain the term *coherent source* in terms of either phase constancy or same frequency etc. Explanations involving both ideas were rare.

(b) (i) The observation of varying sound levels was often described baldly in terms of constructive or destructive interference (a simple mark given the use of the term in the stem) but only rarely were there good and convincing descriptions of either constructive (using ideas of the waves adding in phase) or destructive (180° out of phase). The term 'out of phase' with no angle specified is used frequently and erroneously by candidates.

(ii) The calculation was often well done and clearly demonstrated. Common errors involved the insertion of a factor of two, or the use of a diffraction formula.

15 Part (a) (ii) was answered well by many who knew the terminology very well; most gained three or four marks. The majority of the candidates who did not gain any marks had misinterpreted the words 'describe the formation' to mean 'describe the appearance' rather than 'how and why are they formed'.

Most candidates correctly rearranged the double slit formula in (a) (iii). It was then surprising that very few candidates realised they had to divide 3.6 by 4 to get the fringe spacing and this limited them to a maximum of two marks. Again many candidates who understood how to answer the question then failed to get to grips with the powers of ten and dropped marks.

Most candidates did not gain any marks in part (b) and only very few gained full marks. Part of the problem was that many believed that a single continuous spectrum would appear or that each fringe would be a different colour. A useful exercise to overcome candidate's difficulties with descriptive answers could be to show interference phenomena and ask students to write a detailed description as they are observing the pattern.

16 (a) (i) Too many were unable to recognise that a first and third fringe have just two (rather than three) fringe spacings between them. A common error was therefore to quote an answer of 0.073 m.

(ii) Despite the possible error in (a)(i), many were able to go forward and calculate the wavelength of the ultrasound correctly (via an error carried forward if necessary). This was generally done very well with a good level of detail in the calculation.

(b) On the other hand, this description and explanation was poor. Candidates had to compare the double slit pattern with the diffraction pattern that appears if one slit is covered. Very few described the diffraction pattern with any accuracy and even fewer were able to say how it arose. Descriptions of the physics of the original interference pattern were better but still not always convincing. Examiners were left with the inevitable conclusion that candidates had not considered the phenomena tested here in sufficient depth to answer the question.

18 Whilst it was generally recognised in part (a) that coherent sources provide waves of the same wavelength (or frequency), the requirement about phase was less well understood. The common answer was that the waves must be ‘in phase’, whilst the accepted answer was that there has to be a *constant phase relation* between them. Although monochromatic sources that are in phase will be coherent, coherence does not *require* the sources to be in phase. In part (b), the single monochromatic source is the reason for fulfilling the same *A* criterion; this was correctly quoted by most. Satisfactory explanations of how the phase criterion is satisfied were very rare indeed, with few references to the paths SS_1 and SS_2.

Had part (c) required candidates to sketch Young’s fringes, there can be no doubt that the responses would have been much more rewarding. Most candidates were unable to translate their knowledge of the appearance of a familiar phenomenon into the required intensity/position graph. Near the centre of the pattern, the fringes are all of very similar intensity and all should have been drawn with the same width as the central fringe. The majority of wrong answers showed either the single slit diffraction pattern, or fringes having the same width as the central one but with much lower intensity.

19 This was a long question worth 15 marks and it is pleasing to report that almost all candidates were able to gain a reasonable mark, with some gaining high marks.

In part (a)(i) most candidates knew that light was diffracted from each of the pair of narrow slits and that interference fringes were produced and could be seen in the overlap area. Some candidates referred to coherence in terms of waves being emitted in phase rather than with a constant phase difference. Most candidates were able to explain how a bright fringe or a dark fringe was formed and were able to relate their statements correctly to the path difference or phase difference. A significant number of candidates did not make it clear that a phase difference of 180° is necessary for cancellation of two waves, and often just stated that the waves were out of phase.

In part (a)(ii), it was clear that many candidates did not know the meaning of 'opaque' and thought that some light would pass through the opaque object. Few candidates realised that the fringes seen in (a)(i) would no longer be seen, but a small minority knew that single slit diffraction would take place and were thus able to give a satisfactory description.

Most candidates were aware in part (b)(i) that the fringes would be closer but few were able to give an adequate explanation of why this was so and only the best candidates were able to quote and use the appropriate expression to justify their answer. In part (ii) most candidates gave a correct calculation without any difficulty, but some candidates were unable to make any progress because they calculated the critical angle for a boundary with air. In part (iii) many candidates scored all three marks with a clear, correct diagram. The main reason for not scoring full marks was usually a failure to give the correct point of incidence.

20 (a) (i) Surprisingly few candidates were able to show the path difference clearly. This was considered to be an easy beginning to the question considering that knowledge of this distance is the first basic step in determining whether a signal is maximum or minimum at a given point.

(ii) There were many good thorough answers to this part. Even candidates who could not identify what the path difference was in (i) were able to produce a clear answer in many instances. Some candidates spoiled their answer by being specific and stating that the path difference had to be a half wavelength. The phase difference resulting from the different path lengths was the most commonly overlooked point.

(iii) Candidates usually gained credit for showing the spreading of waves at a slit but fewer explained clearly that this diffraction was necessary to produce two coherent sources or overlapping beams, which then interfered. Many ignored the question and proceeded to describe the conditions for maxima and minima.

(b) This part was usually well done. Some candidates spoiled their attempt by doubling the answer obtained using the correct formula.

(c) (i) This was completed successfully by the majority of the candidates although there was a reluctance to give the unit as m. Many tried to deduce a composite formula and many of these attempts were unsuccessful.

(ii) Many good answers were given in this part. Candidates were able to undertake a variety of relevant calculations but the most important feature of an explanation was that the fringe spacing would be too small to be visible. Some candidates were clearly confused between slit width and slit separation. These candidates often deduced the ratio of λ / d and then wrote about the need to have a slit width of the same order as the wavelength to produce diffraction. Candidates need to be more sceptical about such a statement as in a typical Young's slits experiment fringes are visible although this condition is clearly not met. A few candidates appreciated that for the same slit width less diffraction would take place and therefore there would be less likelihood of the beams overlapping within 0.6 m.

21

(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.