A-Level Physics

Progressive Waves

Mark Scheme

Time available: 70 minutes
Marks available: 51 marks

1. (a) Use of $f = \frac{1}{T}$ or number of waves = $\frac{6 \times 10^{-9}}{\text{their } T}$ ✓

2.3×10^{6} ✓

Condone POT error in MP1

2

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

OR

Divides their distance by 2

OR

Difference in travel time divided by 2 ✓

1.6×10^{3} (m) ✓

2

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

(n_2 =) 1.3(1) ✓

2

(d) Use of $n = \frac{c}{c_s}$ or use of $c = f\lambda$ ✓

*Ecf from **(c)** in use of n = $n = \frac{c}{c_s}$ and condone their c in use of $c = f\lambda$*

6.0×10^{-7} (m) ✓

*Ecf from **(c)***

Answer = 6.1×10^{-7} (m) for n = 1.3

2

[8]

2. (a) f (from $\frac{1}{T}$) in range 61 ± 1 Hz $_1$✓ $_2$✓

OR

61 ± 3 Hz $_{12}$✓

maximum 1 mark for POT error OR incorrect rounding

no credit for 1 sf; treat 60 as 2 sf unless clearly rounded to 6×10^1

*for $_1$✓ $_2$✓ **require ≥ 2 sf** that rounds to not less than 60 and not more than 62*

*for $_{12}$✓ **require ≥ 2 sf** that rounds to not less than 58 but less than 60*

OR

*for $_{12}$✓ **require ≥ 2 sf** that rounds to more than 62 but not more than 64*

if incorrect rounding leads to 60 treat this as 1 sf and give no credit

use of $\frac{1}{T}$ does not have to be seen; marks are for final answer seen

2

(b) (figures) 804 and 226 seen in working $_1$✓

λ = difference between their readings × 2;

given to nearest mm; expect 1.156 (m)

OR

to nearest cm; expect 1.16 (m) $_2$✓

for $_1$✓ 578 is not enough

for $_2$✓ range is based on x = (804 – 226 =) 578 ± 2mm;

give no credit for POT errors eg 115.6 / 116 etc

accept 1156 mm etc if unit on answer line is amended

2

(c) c correctly evaluated to ≥ 2 sf from their f × their λ ✓

substituted data may be from 03.1/2 final answers or unrounded (intermediate) data from working

expected answer = 61 × 0.578 × 2 = 70.5 m s–1

1

(d) μ correct to 2 sf based on their f and their λ earns both marks $_1$✓ $_2$✓

for incorrect / missing μ

EITHER

use of $c = \sqrt{\frac{T}{\mu}}$

OR

use of $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

for $_1$✓ their value of μ can be given to ≥ 2 sf but must agree with $\frac{0.5 \times g}{(\text{their } f \times \lambda)^2}$ OR $\frac{0.5 \times g}{(\text{their } c)^2}$ ***when rounded to 2 sf****; use of g = 9.81 or 9.8 only; no ecf for mixed units*

expected answer $\mu = 9.9 \times 10^{-4}$ (kg m^{-1}): be wary of which approach has been taken by the candidate

for $_{12}$✓ 'use of' means allow ***either***

rearranges so that μ is the subject eg $\mu = \frac{T}{c^2}$

(accept $\mu = \frac{mg}{c^2}, \frac{T}{c^2} = \mu$ *etc)* ***or***

substitution of all relevant data including their c into a correct expression with μ as the only unknown

for T allow 4.9 / 4.91 / 4.905 (accept 0.5 × 9.81 or 0.5 × 9.8); allow mixed units; allow 0.5g

OR 'use of' means allow ***either***

rearranges to $\mu = \frac{T}{(2 \times l \times f)^2}$ OR $\frac{T}{4 \times l^2 \times f^2}$ ***or***

substitution of all relevant data including their l and f leaving μ as the unknown; allow sub of λ for $2l$

watch for possible error $\lambda = L$

2

(e) 0.71 (mm) ✓

only answer that gets mark

1

(f) ANY TWO FROM

repeat readings at different points along the rod and calculate an average / mean $_1$✓

repeat readings in different directions (perpendicular to the rod) and calculate an average / mean $_2$✓

reject / discard anomalous readings before calculating an average / mean $_3$✓

award $_{123}$✓= 1 MAX for checking at different points / in different directions to confirm that the rod is uniform / that there are no anomalies

allow 'cylinder' / 'wire' etc for rod

for $_1$✓ $_2$✓ and $_3$✓ averaging idea only needs to be seen once;

if averaging idea missing then allow 'repeat at different points and in different directions, then remove anomalies' $_{123}$✓= 1 MAX

if 'calculate' is not seen allow 'work out' / /'determine' / 'compute'; anything that sounds like a mathematical process is ok;

'find' / 'obtain' / 'take' / 'do an average' are just ok;

'get' is not ok

for $_1$✓ allow repeat at 'different positions' / 'down / along the rod'

for $_2$✓ allow (repeat in different directions) 'around the rod' / 'different orientations' / 'angles' / 'planes' / 'sides'

for $_3$✓ allow 'ignore anomalies'; 'outlier' = 'anomaly'

reject 'calculate an average to eliminate effect of anomalies'

treat as neutral: 'turn the wheel to close the callipers' / suggestions about calibration

treat as neutral: 'zero callipers before use' this is a procedure to eliminate a source of systematic error

2

(g) (for use of expected 0.71)

ρ = 8.9(41) × 10^3 (kg m^{-3})

OR

(for use of 0.53)

ρ = 1.6(05) × 10^4 (kg m^{-3})

OR

$$\rho = \frac{4.51\times10^{-3}}{(\text{their } d \text{ from (e)})^2}$$

OR

attempts to use μ OR 3.5(4) × 10^{-3} divided by their (recognisable) cross-sectional area $_1$✓

AND/OR

evidence showing cross-sectional area = $\frac{\pi d^2}{4}$ using their d from (e) (allow πr^2 using their d) $_2$✓

correct answer scores $_{123}$✓✓✓

for $_{123}$✓✓✓ allow an answer that rounds to the correct 2 sf value

sample results for expected d

d/mm	A/m^2	ρ/kg m^{-3}
0.71	3.96×10^{-7}	$8.9(41) \times 10^3$
0.53	2.21×10^{-7}	$1.6(05) \times 10^4$

for $_1$✓ accept use of symbols, eg

$$\rho = \frac{\mu}{A} \; / = \frac{3.54\times10^{-3}}{A(\times 1)} \; / = \frac{4\times\mu}{\pi\times d^2} \; / = \frac{4\times 3.54\times10^{-3}}{\pi\times d^2(\times 1)}$$

$$= \frac{3.54\times10^{-3}}{\pi\times r^2(\times 1)}$$

for $_2$✓ expect correct value of A seen or correct values of A or d in working, eg

$$\rho = \frac{3.54\times10^{-3}}{3.96\times10^{-7}(\times 1)} / = \frac{4\times 3.54\times10^{-3}}{\pi\times(0.71\times10^{-3})^2\times(1)}$$

accept values ≥ 2 sf for A; allow ecf d and don't penalise POT error in A or d (eg missing 10^{-7}, 10^{-3})

1
2

[13]

3. (a) Waves travel to the boundaries and are reflected ✓

Not bounce off ...

1

two waves travelling in opposite directions interfere/superpose ✓

Not superimpose or interferes with itself

1

Fixed boundaries (cannot move so) are nodes ✓

creates nodes and antinodes bland = 0

In some positions the waves always cancel /interfere destructively to give zero amplitude/no vibration/nodes)
OR
interfere constructively to produce positions of maximum amplitude/maximum vibration/antinodes ✓

1
Max 3

(b) Use of $f=\frac{1}{2l}\sqrt{\frac{T}{\mu}}$ ✓

Either rearranges for μ without substitution or substitutes correctly in the formula

1

4.2 (4.19) × 10^{-4} (kg) ✓

1

(c) 240 (244) (m s^{-1})

1

(d) 1 rotation of the peg = 22 mm ✓

Or Reads increase in tension produced by the extra extension (about 10 N) from graph and adds to 25

1

extra extension = 22 × 75/360 = 4.6 mm

(ecf for incorrect circumference) ✓

πd × 75/360 not evaluated =1

1

Total extension = 11 + 4.6 (15.6 mm) so tension 35 - 36N ✓

Inspect their length and their tension in the substitution

1

Calculates frequency **for their tension**

T must <u>be greater than</u> the original 25N

Condone adding or subtracting <u>extra</u> extension to 0.33 m

If 4.0 × 10^{-4} kg used then answer will be in range 448 Hz to 455 Hz

If 4.19 × 10^{-4} used 438 to 444 Hz

1

[10]

4. (a) Period = 0.2 × 10^{-14} (s) read off

OR

Recognisable T substituted into $T = 1 / f$ ✓

An acceptable subject (period, time for one cycle, one cycle, T, etc.)

Allow non-standard symbol with unit seen on time.

Allow this subtraction of two times seen in $f = 1/T$

Use of $T = 1 / f$ and $c = f\lambda$ ✓

OR

Use of $\lambda = cT$

Use of here is:

Subject must be seen with substitutions or rearranged equations with $f = 1/T$ and $\lambda = c/f$

Condone power 10 error here

Condone lack of subject in vertical working where rearranged equation with appropriate subject seen at heading of column

6(.0) × 10^{-7} (m) ✓

Number must be expressed as 6 × 10^{-7} or 600 × 10^{-9}

or equivalent not enough to see only nano prefix.

3

(b) (Determines a fraction of cycle)

$\frac{0.04}{0.2}$ or $\frac{2}{10}$ or $\frac{1}{5}$ or 0.2 or $\frac{1.2(\times 10^{-7})}{6(\times 10^{-7})}$ or 0.2λ seen ✓

Condone their fraction × 2π or their decimal × 2π

For 1st mark

2π/5 OR 0.4 π

OR

1.26 or 1.3 ✓

Allow 8π/5 OR 1.6 π

OR

5.03 or 5.0

2

(c) (Distance =) $3 \times 10^{-7} \times 2.37 \times 10^{5}$ seen

OR

(Distance =) 0.07(11) (m) seen ✓

Subs into $s = \frac{1}{2}at^2$ ✓

Condone error in sub for s where formula has been otherwise correctly manipulated with a (or g) as subject

9.88 (3 sf only) ✓

Alternative:

1st mark *average speed* $= \frac{3 \times 10 - 7 \times 2.37 \times 105}{0.12}$

2nd mark $a = \frac{2 \times \text{their average speed}}{0.12}$

3rd mark *9.88*

3

(d) Draws a tangent to the curve at approximately

t = 120 ms and attempts a gradient calculation ✓

Tangent must be a straight line that touches curve and divergent from curve before 90 ms and after 150 ms

(Gradient =) 1.2 (range 1.1 to 1.3) ✓

Allow 1.2 × 10–3 (range 1.1 × 10–3 to 1.3 × 10–3) ✓

Ignore units on answer line

2nd mark is dependent on 1st mark

Max 1 mark for correct answer in range where tangent satisfies above conditions but doesn't quite touch curve (half-square tolerance)

First alternative:

1st mark

Use of v = u +at with sub for a = 9.88 or 9.875 ***and*** *t=0.12*

2nd mark

1.2 or 1.19 or 1.185 ***only***

Second alternative:

1st mark

Use of s = 1/2at2 and ds/dt = at with sub for a = 9.88 or 9.875 ***and*** *t = 0.12*

2nd mark

1.2 or 1.19 or 1.185 ***only***

4

(e) (instantaneous) Velocity (of the mirror) or (instantaneous) speed (of the mirror) ✓

Ignore any units quoted

Do not allow:

Average speed / constant speed

4

[8]

5. (a) π / 180° out of phase ✓

*Do **not** allow "out of phase".*

1

(b) wavelength = 0.44 m ✓

c (= $f\lambda$) = 145 (m s^{-1}) ✓

2

(c) First harmonic frequency = 110 Hz✓

$T = 4 \times 110^2 \times 0.66^2 \times \left(\frac{3.1\times10^{-8}}{0.91}\right)$ ✓

71.8 N✓

3

(d) Extension of string = $3 \times 2\pi \times 3.0 \times 10^{-3}$ (= 5.65 cm)✓

energy stored = 0.5 × 71.8 × 0.0565 = 2.03 (J)✓

Compares calculated energy quantitatively to another energy and draws correct inference, e.g. wire would be moving at about 80 mph so a risk / 2 J is the equivalent of 1 kg mass dropped through 0.2 m so a risk✓

3

[9]