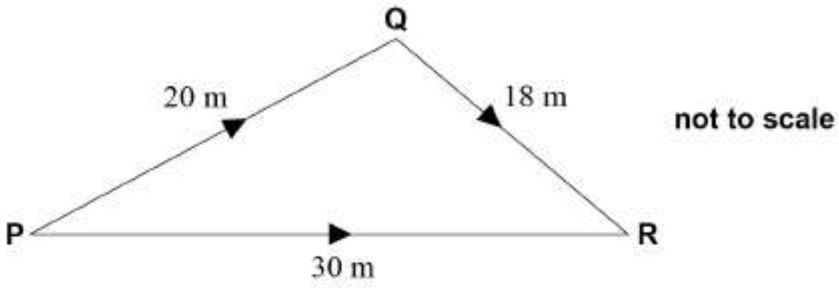
## Session 4 – Question Pack (Waves & Quantum)

## Waves – Superposition and Interference

### Q1.

In the diagram, **P** is the source of a wave of frequency 50 Hz




The wave travels to **R** by two routes, **P** → **Q** → **R** and **P** → **R**. The speed of the wave is 30 m s−1

What is the path difference between the two waves at **R** in terms of the wavelength $\lambda$ of the waves?

**A** $4.8\lambda$ ⬭

**B** $8.0\lambda$ ⬭

**C** $13.3\lambda$ ⬭

**D** $20.0\lambda$ ⬭

**(Total 1 mark)**

### Q2.

Two coherent sources generate sound waves of wavelength 0.40 m. The waves leave the sources in phase. A detector some distance from the sources receives the sound waves. The path difference between the detector and the sources is 0.90 m.

What is the phase difference between the waves arriving at the detector?

**A** zero ⬭

**B** 45° ⬭

**C** 90° ⬭

**D** 180° ⬭

**(Total 1 mark)**

## Q3.

Two loudspeakers emit sound waves.

Which line in the table gives the correct frequency condition and the correct phase condition for the waves from the loudspeakers to be coherent?

| | Frequency condition | Phase condition | |
|---|---|---|---|
| **A** | same frequency | variable phase difference | ○ |
| **B** | constant frequency difference | constant phase difference | ○ |
| **C** | constant frequency difference | in phase | ○ |
| **D** | same frequency | constant phase difference | ○ |

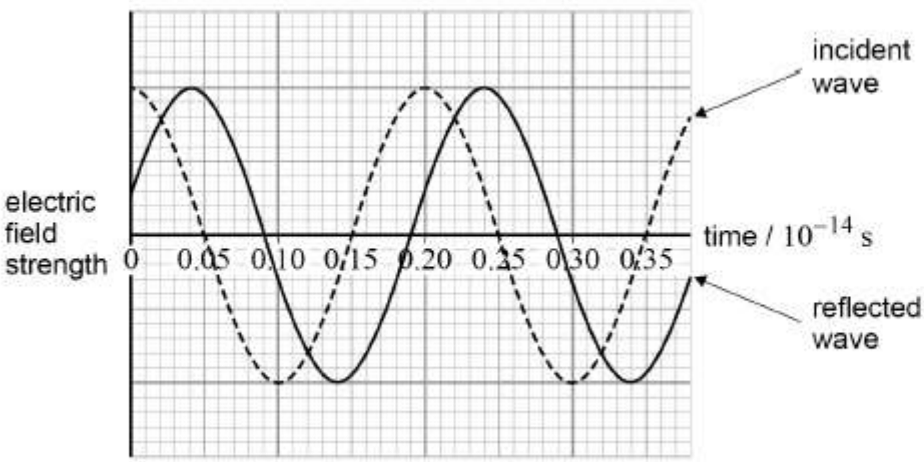
**(Total 1 mark)**

## Q4.

Monochromatic light is reflected normally off a mirror, creating interference between the incident and reflected waves. The mirror is released from rest and falls, causing a change in the phase difference between the incident and reflected waves at a detector.

**Figure 1** illustrates the phase relationship between the incident and reflected waves at the detector for one position of the mirror.

**Figure 1**




(a) Show that the wavelength of the light is 600 nm

**(3)**

(b) Determine the phase difference, in rad, between the incident and reflected waves shown in **Figure 1**.

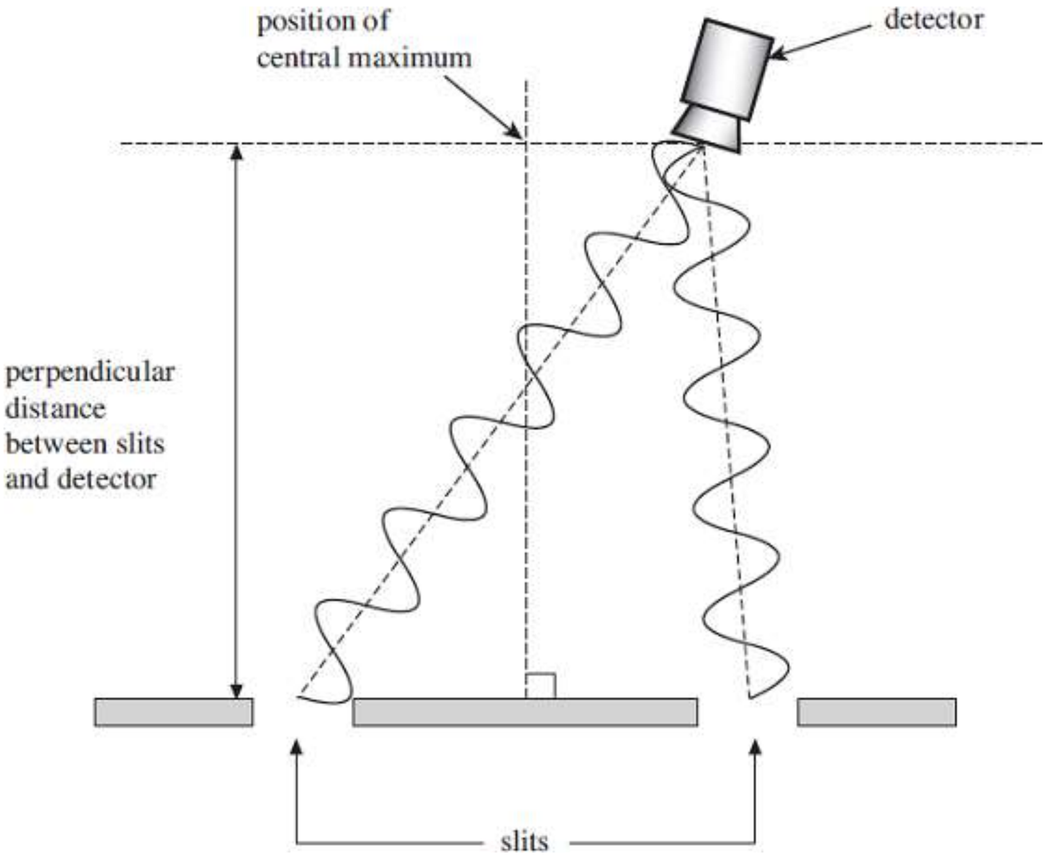
phase difference = ____________________________ rad

**(2)**

**(Total 5 marks)**

## Q5.

The diagram below shows the paths of microwaves from two narrow slits, acting as coherent sources, through a vacuum to a detector.




(a) Explain what is meant by *coherent sources.*

______________________________________________________________________

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______________________________________________________________________

**(2)**

(b) (i) The frequency of the microwaves is 9.4 GHz.

Calculate the wavelength of the waves.

wavelength = ____________________ m

**(2)**

(ii) Using the diagram above and your answer to part (b)(i), calculate the path difference between the two waves arriving at the detector.

path difference = ____________________ m

**(1)**

(c) State and explain whether a maximum or minimum is detected at the position shown in the diagram above.

___________________________________________________________________

___________________________________________________________________

___________________________________________________________________

___________________________________________________________________

**(3)**

**(Total 8 marks)**

**Two Source Interference**

**1.** The figure below shows two identical monochromatic light sources $\mathbf{S_1}$ and $\mathbf{S_2}$ placed in front of a screen. The sources emit light in phase with each other.


(i) State, in terms of the path difference of the waves, the conditions necessary to produce

**1** constructive interference at point **P** on the screen

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..........................................................................................................................

[1]

**2** destructive interference at point **Q** on the screen.

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[1]

(ii) The light sources $\mathbf{S_1}$ and $\mathbf{S_2}$ are 0.50 mm apart. They each emit light of wavelength $4.86 \times 10^{-7}$ m. An interference pattern is produced on the screen placed 2.00 m from the sources. Calculate the distance between two neighbouring bright fringes on the screen.

distance = ..................................................... m

[3]

(iii) Suggest how the appearance of the interference pattern would change if coherent **white** light sources were used instead of the monochromatic sources.

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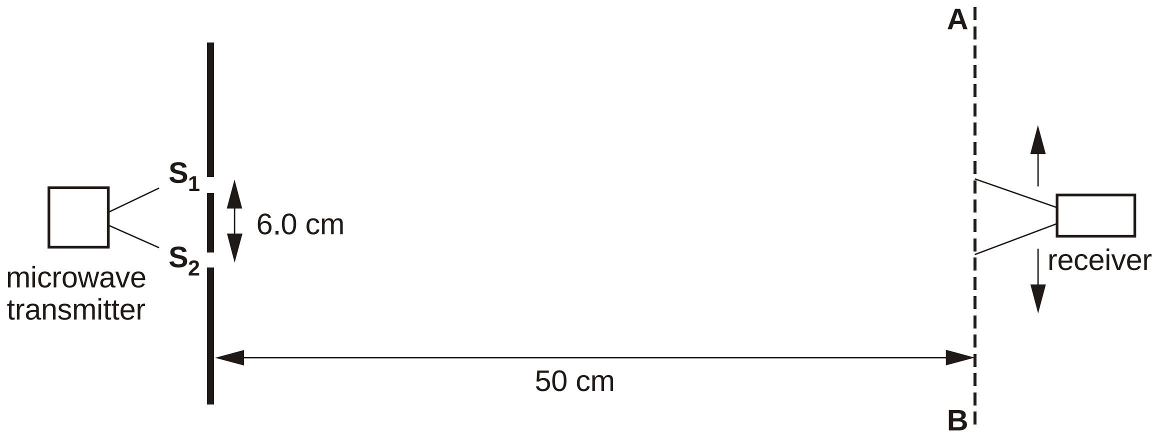
[2]

[Total 7 marks]

**2.** The figure below shows an arrangement to demonstrate interference effects with microwaves. A transmitter, producing microwaves of wavelength 3.0 cm, is placed behind two slits 6.0 cm apart. A receiver is placed 50 cm in front of the slits and is used to detect the intensity of the resultant wave as it moves along the line **AB**.




(i) Explain, in terms of the **path difference** between the waves emerging from the slits $S_1$ and $S_2$, why a series of interference maxima and minima are produced along the line **AB**.

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[3]

(ii) Assuming that the interference of the microwaves is similar to double slit interference using light, calculate the distance between neighbouring maxima along the line **AB.**

distance = ..................................... cm

[3]

(iii) The microwaves from the transmitter are *plane polarised*. State what this means and suggest what would happen if the receiver were slowly rotated through 90° while still facing the slits.

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[2]

[Total 8 marks]

# Standing (Stationary) waves

**1.** This question is about progressive waves and stationary waves.

Which statement is **not** correct?

**A** A progressive wave transports energy through space.

**B** A stationary wave must have at least one node.

**C** For both waves, the amplitude of the oscillation is the same everywhere along the wave.

**D** In the stationary wave, the oscillations of the particles at two adjacent antinodes are out of phase by 180°.

Your answer ☐ **[1]**

**2.** The stretched wire of fixed length is used in an experiment to demonstrate stationary waves. The tension in the wire is kept **constant**.
Fig. 26 shows the three stationary wave patterns that can be formed on the stretched wire.

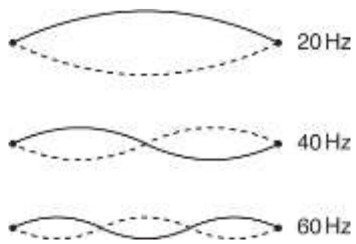


**Fig. 26**

The frequency *f* of vibration of the stretched wire for each stationary wave is shown on Fig. 26. Use Fig. 26 to describe and explain how the wavelength *λ* of the progressive wave on the stretched wire depends on the frequency of vibration of the wire.

**[3]**

**3.** Stationary waves are produced in a tube closed at one end and open at the other end. The fundamental frequency is 120 Hz.

What is a possible frequency of a harmonic for this tube?

**A** 60 Hz

**B** 240 Hz

**C** 360 Hz

**D** 480 Hz

Your answer [1]

**4(a).** A guitar manufacturer wants to investigate the quality of sound produced from a new uniform polymer string. **Fig. 18.1** shows the string which is kept in tension between a clamp and a pulley. The frequency of the mechanical oscillator close to one end is varied so that a stationary wave is set up on the string.

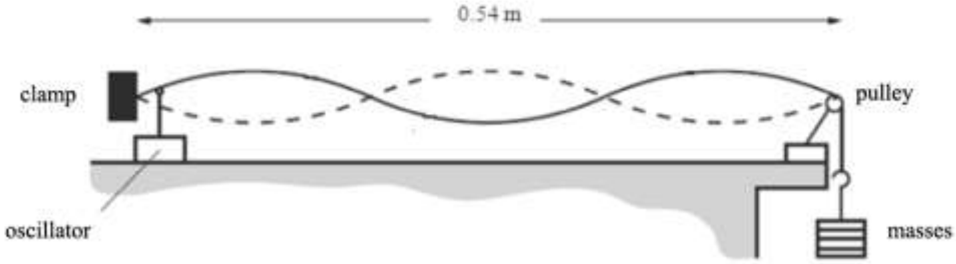


**Fig. 18.1**

Explain how the stationary wave is formed on this stretched string.

[2]

**(b).** The frequency of the oscillator is 60 Hz.

Use Fig. **18.1** to calculate the speed of the transverse waves on the string.

speed = ........................................... m $s^{-1}$ **[3]**

**(c).** The speed $v$ of the transverse waves on the string is directly proportional to $\sqrt{T}$, where $T$ is the tension in the string.
The tension $T$ in the string is increased by 14 %. The frequency $f$ of the oscillator is adjusted to get the same stationary wave pattern as **Fig. 18.1**.

Calculate the percentage increase in the frequency $f$.

increase = .......................................... % **[2]**

**5.** Fig. 4.2 shows a section of string held under tension between a clamp and a pulley, 80 cm apart. A mechanical oscillator is attached to the string close to the clamped end. The frequency of the mechanical oscillator is varied until the stationary wave shown is set up between the clamp and the pulley. The same four points as in Fig. 4.1 are marked on the string.

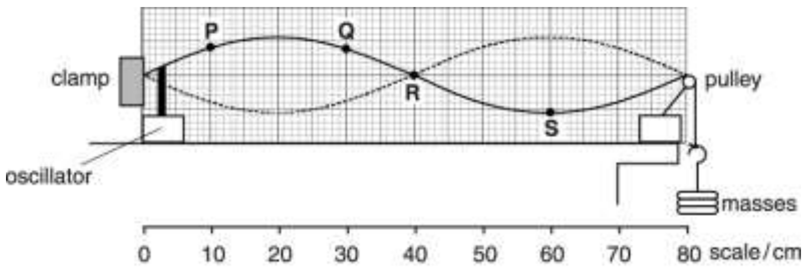


**Fig. 4.2**

i. Describe how a stationary wave is different from a progressive wave.

**[2]**

ii. Explain how the stationary wave is formed on this string.

**[3]**

iii. Describe, using the terms amplitude, frequency and phase difference, how the motions of the points **P**, **Q** and **S**

1. are similar,

2. are different.

iv. In Fig. 4.2 the frequency of oscillation is 30 Hz. State, with a reason, the lowest frequency of oscillation of the string at which the motions of all of the points **P**, **Q**, **R** and **S** are

1. in phase,

2. all at rest.

**[4]**

**6(a).** An estimation of the speed of electromagnetic waves can be made using the hot spots inside a microwave oven. Microwaves are emitted in all directions inside the metal walls of the oven at a frequency of $2.5 \times 10^9$ Hz causing stationary waves to be set up. Fig. 7.1 shows a typical pattern of the centres of the hot spots marked **X** in the central area of the floor of the oven.

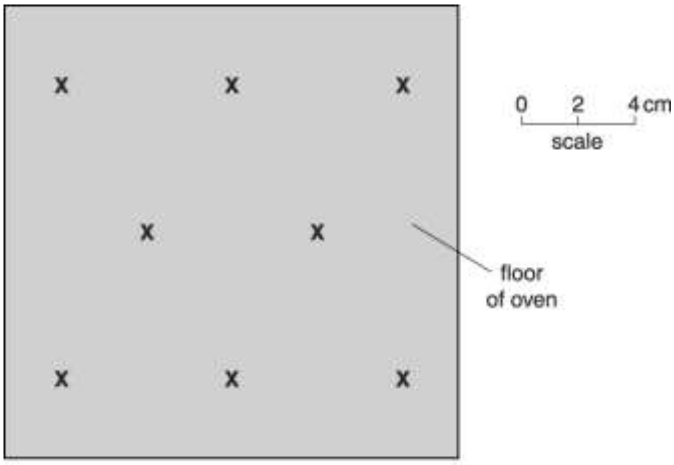


**Fig. 7.1**

These positions can be located to within a few millimetres by melting small areas in a bar of chocolate placed on the floor of the oven for a few seconds.

Explain how a stationary microwave pattern is set up in the oven.

**[3]**

**(b).** Explain whether the points marked **X** on Fig. 7.1 are at nodes or antinodes in the wave pattern.

**[2]**

**(c).** Fig. 7.1 is drawn to **half scale**. By using measurements taken from the diagram make an estimate of the speed c of the microwaves. Make your reasoning clear.

$c$ = ........................................................ m $s^{-1}$ **[4]**

## Waves – Superposition and Interference

### Q1.

**C**

**[1]**

### Q2.

C

**[1]**

### Q3.

D

**[1]**

### Q4.

(a) Period = $0.2 \times 10^{-14}$ (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 $6 \times 10^{-7}$ or $600 \times 10^{-9}$*

*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 0.2$\lambda$ 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

**[5]**

## Q5.

(a) same wavelength / frequency ✓

constant phase relationship ✓ allow 'constant phase difference' but not 'in phase'

2

(b) (i) ( $\lambda = \frac{c}{f}$ )

*Use of speed of sound gets zero*

$3.00 \times 10^8 = 9.4\ (10^9)\ \lambda$ OR $\frac{3.00\times10^8}{9.4\times(10^9)}$ ✓

$= 3.2 \times 10^{-2}$ ($3.19 \times 10^{-2}$ m) ✓

*Allow 0.03*

2

(ii) $3.2 \times 10^{-2}$ ✓ (m) ecf from bi

*Don't allow '1 wavelength', 1λ, etc*
*Do not accept: zero, 2π, 360 °*

1

(c) maximum (at position shown) ✓

*allow constructive superposition.*
*'Addition' is not enough*

constructive interference / reinforcement ✓

**ecf for 'minimum' or for reference to wrong maximum**

(the waves meet) 'in step' / peak meets peak / trough meets trough / path difference is (n) λ / in phase ✓

3

**[8]**

**Two Source Interference**

| | | | |
|---|---|---|---|
| **1.** | (i) | semicircular wavefronts leaving the gap | B1 |
| | | no change in wavelength stated OR clearly shown (at least 3 waves needed) – judged by eye | B1 |
| | (ii) | LESS diffraction would occur – shown or stated | B1 |
| | | wavefronts mainly plane (by eye) (allow curved at edges) | B1 |
| | (iii) | MORE diffraction for SOUND | B1 |
| | | Wavelength of sound > wavelength of light (WTTE) | B1 |
| | | Valid comparison of wavelength of light or sound with doorway e.g. doorway of similar size to wavelength of sound OR wavelength of light is very small compared to door (WTTE) | B1 |

[7]

| | | | |
|---|---|---|---|
| **2.** | (i) | **1.** path diff. = n$\lambda$ (where n = 0,1,2 etc) {allow 0, OR $\lambda$, OR 2$\lambda$ etc} | B1 |
| | | **2.** path diff = (n + ½)$\lambda$ (where n = 0,1,etc) {allow = 0.5$\lambda$ OR,1.5$\lambda$, etc} | B1 |
| | | {do not allow answers purely about phase diff. e.g. with degrees or $\pi$ used and no ref to $\lambda$} | |
| | (ii) | recall of formula $\lambda$ **= ax/D** | C1 |
| | | correct substitution for a, $\lambda$ and D: e.g. $\times = (4.86 \times 10^{-7} \times 2)/0.5 \times 10^{-3}$ | C1 |
| | | **x = 1.94** $\times$ **10**$^{-3}$ **m** (1.9 or 1.944) | A1 |
| | (iii) | **central white** fringe | B1 |
| | | other fringes are **coloured** (WTTE: e.g. allow spectrum formed) | B1 |

[7]

| | | | |
|---|---|---|---|
| **7.** | (i) | constructive interference/waves in phase for maxima OR destructive interference/waves 'out of phase' | C1 |
| | | maxima produced when path difference is 0 OR n$\lambda$ (WTTE) | A1 |
| | | minima produced when path difference is (n+1/2) $\lambda$ (WTTE) | A1 |
| | | NB answers that do not account for SERIES of both maxima and minima can score maximum of 2 marks only) | |
| | (ii) | recall of $x = \lambda D/a$ | C1 |
| | | {expressed in any form; allow unusual symbols if correctly identified} | |
| | | correct substitution: $x = (3.0 \times 50)/6$ | A1 |
| | | $x$ = 25 cm | A1 |
| | (iii) | microwaves vibrate/oscillate/displaced in one plane (WTTE) | B1 |
| | | {do not allow travel/propagate in one plane) | |
| | | signal decreases to zero (WTTE) | B1 |

[8]

## Standing (Stationary) Waves

| Question | | | Answer/Indicative content | Marks | Guidance |
|---|---|---|---|---|---|
| 1 | | | **C** | 1 | |
| | | | **Total** | **1** | |
| 2 | | | Speed / $v$ (of the progressive wave) is the same<br><br>Wavelength / $\lambda$ decreases as frequency / $f$ increases<br><br>length = $\lambda/2$ (for the first harmonic), length = $\lambda$ (for the second harmonic) and length = $3\lambda/2$ (for the third harmonic) | **B1**<br><br>**B1**<br><br>**B1** | **Allow** $f \propto 1/\lambda$ or $\lambda$ is halved when $f$ is doubled (AW)<br><br>**Allow** $L$ for length<br>**Allow** $\lambda = 2L / n$ ($n$ is 1, 2 and 3)<br>**Not** just $\lambda/2$, $A$ and $3\lambda/2$ next to the patterns<br><br>**Examiner's Comments**<br>Full marks were rarely scored but many top-end candidates did manage to score two marks for recognising that the wavelength was inversely proportional to frequency and that the speed of the progressive wave was constant. A significant number of candidates recognised that the separation between adjacent nodes was half a wavelength, but then spoilt their answers by mentioning *'wavelength = 0.5λ for the first harmonic and wavelength = 1.5λ for the third harmonic'.* The answers from weaker candidates were confused with statements such as '20 Hz = 0.5λ'. |
| | | | **Total** | **3** | |
| 3 | | | **C** | **1** | |
| | | | **Total** | **1** | |
| 4 | a | | Waves are reflected at the pulley end. | B1 | |
| | | | This produces nodes and antinodes on the string. | B1 | |
| | b | | $\lambda / 2 = 0.54 / 3 = 0.18$ m | C1 | |
| | | | $\lambda = 0.18 \times 2 = 0.36$ (m) | C1 | |
| | | | $v = 60 \times 0.36$; speed = 21.6 m $s^{-1}$ ≈ 22 (m $s^{-1}$) | A1 | |

| | | | | | |
|---|---|---|---|---|---|
| | c | | $v \propto f$ and since $v \propto \sqrt{T}$, therefore $f \propto \sqrt{T}$ | C1 | |
| | | | frequency will increase by a factor of $\sqrt{1.14}$ = 1.068, therefore increase = 6.8% | A1 | |
| | | | **Total** | **7** | |
| 5 | | i | *progressive* a wave which transfers energy | B1 | **accept** phase relationship descriptions between |
| | | i | *stationary* a wave which traps / stores energy (in pockets)<br>**or** *progressive* : transfers shape / information from one place to another<br>*stationary* where the shape does not move along / which has nodes and antinodes / AW | B1 | different points on wave;<br><br>must be a comparison for same property to score both marks |
| | | i | the wave reflected (at the fixed end of the wire) | B1 | |
| | | i | interferes / superposes with the incident wave<br>to produce a resultant wave with nodes and antinodes / no | B1 | |
| | | i | energy transfer | B1 | |
| | | ii | **(all** points have) same frequency | B1 | |
| | | ii | **P** and **Q** have same amplitude and (are in) phase | B1 | **allow** *same phase difference* here |
| | | ii | **S** has larger amplitude than **P** and **Q** | B1 | **allow** *different to* |
| | | ii | **S** has a phase difference of Φ / in antiphase to **P** and **Q** | B1 | **or** 180° **max** any 3 out of 4 marking points |
| | | iii | 15 Hz | B1 | |
| | | iii | as all points in the fundamental / first harmonic mode move in phase | B1 | **accept** string is 1/2 λ long / between ends |
| | | iii | 120 Hz | B1 | |
| | | iii | for every 10 cm to be at rest ? = 20 cm (so 4 × frequency of Fig. 4.2) | B1 | **accept** as all points are nodes **or** $f = 8f_0$ **or** is 8$^{th}$ harmonic<br><br>**Examiner's Comments**<br><br>In part (i) many candidates gave only the characteristics of a stationary wave failing to give the comparison property for a progressive wave. Part (ii) was answered well by all. In part (iii) most candidates were aware that all points oscillated with the same frequency but failed to give |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | enough detail to score further marks. In part (iv) many candidates did not notice the request for frequency values . It was apparent that few candidates had an understanding of harmonics. About half of the candidates gave at least one correct frequency but the explanation for the choice was often not convincing. |
| | | | **Total** | **12** | |
| 6 | a | | (micro)waves are reflected (at the metal walls) | B1 | |
| | | | reflected waves interfere / superpose with the incident waves | B1 | |
| | | | to produce nodes and antinodes (– a stationary wave pattern) | B1 | **allow** points of constructive and destructive interference<br><br>**Examiner's Comments**<br><br>The majority were able to describe successfully how a stationary microwave pattern is set up in the oven. |
| | b | | X are the points of maximum energy / intensity / amplitude | M1 | **allow** displacement in this case |
| | | | so are antinodes | A1 | **Examiner's Comments**<br><br>About half of the candidates were able to state that the crosses were points of maximum amplitude or intensity. Some answers failed to score because a suitable scientific vocabulary was not used. |
| | c | | measurement = 3 cm **or** λ/2 = 6 cm | B1 | measurement to within ± 1 mm |
| | | | so λ = 0.12 m | C1 | **ecf** measurement, i.e. λ = 4 x measurement |
| | | | c = fλ = 2.5 x $10^9$ x 0.12 | M1 | there must be a valid calculation shown |
| | | | = 3.0 x $10^8$ (m $s^{-1}$) | A1 | scores 1 out of final 3 for answer of 1.5 x $10^8$<br>**allow** 1 SF, i.e. 3 x $10^8$<br><br>**Examiner's Comments**<br><br>About one third scored full marks. Many did not write down their initial |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | measurement or else did not make it clear whether their figures referred to the scale diagram or real space. Sometimes this failure led to their own confusion and downfall by providing an answer half of the correct value. |
| | | | **Total** | **9** | |