Mark scheme – Stationary Waves

Question			Answer/Indicative content	Marks	Guidance
1			**D**	1	
			Total	**1**	
2			**C**	1	
			Total	**1**	
3			**C**	1	
			Total	**1**	
4			B	1	<u>**Examiner's Comments**</u> The correct response is **B**. Around two thirds of candidates were able to correctly calculate the frequency; this question relies on the candidate appreciating that there is more than one complete cycle in the tube and then evaluating the correct wavelength. It is then a straightforward calculation. As expected, most of the incorrect responses were **A**, where the wave equation had simply been used with the given numbers. Several candidates drew on the diagram to help in their calculation of the wavelength, although some thought that the wavelength was two thirds of the tube length, rather than four fifths.
			Total	**1**	
5			**A**	1	
			Total	**1**	
6			C	1	
			Total	**1**	
7			**B**	1	
			Total	**1**	
8			**C**	**1**	
			Total	**1**	
9			B	1	
			Total	**1**	
10			C	1	
			Total	**1**	
11			B	1	
			Total	**1**	
12		i	'Inverted' graph	B1	**Ignore** amplitude <u>**Examiner's Comments**</u>

					The majority of the candidates drew the correct variation of the displacement after a time of half a period. In **(a)(ii)**, it was good to see the nodes clearly marked with the letters **N**. The most common mistake was to draw a curve with a different period with nodes at all the points where the displacement was zero.
		ii	Nodes shown correctly	B1	Expect at least 2 nodes labelled **N** No mark if the labels **N** are omitted **Note** the nodes must be on the original graph and not that sketched in **(a)(i)**
			Total	**2**	
13			A progressive wave transfers energy / information (in the direction of the wave)/all points have (the same) amplitude In a stationary wave there is no net energy transfer / energy is stored / has points which are always zero amplitude / or points have different amplitudes	**B1** **B1**	**Note** for two marks there must be a comparison **Allow** stationary wave has nodes (and antinodes) for one mark **Examiner's Comments** Most candidates answered the difference between stationary and progressive waves in terms of energy considerations.
			Total	**2**	
14			$v \propto f$ 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	**2**	
15			Difference: (stationary waves) has nodes / antinodes Similarity: Oscillations are longitudinal	B1 B1	Differences and/or similarities can be described in terms of net energy transfer, phase or amplitude variations **Examiner's Comments** This question is clear that the differences and similarities should be based on the oscillations. Few candidates did this, but other routes could be used to gain credit. Candidates should be careful not to create lists in this style of question and simply produce a single response, as contradictions can be penalised.
			Total	**2**	
16			Waves are reflected at the pulley end.	B1	

			This produces nodes and antinodes on the string.	B1	
			Total	**2**	
17		i	Reflection (of progressive waves) at (fixed) end(s) / **X** / **Y**	B1	
		i	Superposition (of these waves gives rise to the stationary wave)	B1	**Allow**: 'interference' instead of 'superposition' **Examiner's Comments** Most candidates wrote down generic statements about stationary waves and did not address this specific question. About half of the candidates either scored one or two marks by mentioning that the transverse waves were reflected at the fixed ends and the superposition of these waves resulted in the observed stationary wave.
		ii	The wavelength is twice the length of cord / distance between **X** and **Y**	B1	**Allow** λ = 2**XY** or equivalent **Examiner's Comments** Most candidates gave the correct answer; the wavelength of the transverse wave was equal to twice the length of the rubber cord. A small number of candidates thought the inter-nodal separation was a quarter of a wavelength.
			Total	**3**	
18			$\lambda / 2 = 0.54 / 3 = 0.18$ 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	
			Total	**3**	
19			Correct relationship between length of tube and *λ* for at least **two** stationary waves	B1	**Allow** L for length of tube Example $L = \lambda/4$ at 60 Hz, $L = 3\lambda/4$ at 180 Hz $L = 5\lambda/4$ at 300 Hz **Allow** $\lambda/4$ linked to 60 (Hz) etc on diagram or in text **Not** just f increases λ decreases
			speed / *v* is constant **or** $f\lambda$ = constant **or** $f \propto 1/\lambda$	B1 B1	**Note** - calculation can also score the previous B1 mark E.g f increases by a factor of 5 (from 60 Hz to 300 Hz) and λ decreases by the same factor (of 5) **<u>Examiner's Comments</u>**

			Calculation comparing at least **two** stationary waves to show $f\lambda$ = constant **or** $f \propto 1/\lambda$		The majority of the candidates scored 1 mark for either mentioning that the wavelength was *inversely proportional to the frequency* or identifying the correct relationship between the length of the tube and the wavelength. Generally, the explanations lacked cohesion and showed poor comprehension of stationary waves formed within a fixed column of air. The common errors are highlighted below. **Misconception** There were some missed opportunities, with some candidates making the following mistakes. • **wavelength** = $\lambda/4$, $3\lambda/4$ and $5\lambda/4$, instead of **length of tube** = $\lambda/4$, $3\lambda/4$ and $5\lambda/4$. • Correctly identifying the relationship between L and λ, but then confusing L and λ, and stating that the $f \propto \lambda$. • Using an equal sign instead of the proportionality symbol, e.g. *frequency is inversely proportional wavelength, hence* $f = 1/\lambda$.
			Total	**3**	
20			Speed / v (of the progressive wave) is the same Wavelength / λ decreases as frequency / f increases length = $\lambda/2$ (for the first harmonic), length = λ (for the second harmonic) and length = $3\lambda/2$ (for the third harmonic)	**B1** **B1** **B1**	**Allow** $f \propto 1/\lambda$ or λ is halved when f is doubled (AW) **Allow** L for length **Allow** $\lambda = 2L / n$ (n is 1, 2 and 3) **Not** just $\lambda/2$, A and $3\lambda/2$ next to the patterns **Examiner's Comments** 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**	
21	a		tube pushed into water by $\lambda/2$	B1	allow any statement about antinode needed at open end and node at water level.
			therefore $\lambda/2$ = 0.506 − 0.170 giving λ = 0.672 (m)	B1	
			using $v = f\lambda$	C1	

			v = 500 × 0.672 = 336 (m s^{-1})	A1	A solution worked to 2 SF will score a maximum of 3 marks.
	b		smaller λ means smaller *l* to measure, so less accurate measurement.	B1	
			added detail or expansion of argument.	B1	
	c		the wave reflected at the end of the pipe interferes / superposes with the incident wave.	B1	
			to produce a resultant wave with nodes and antinodes.	B1	
			both ends must be antinodes **or** the pipe must be nλ/2 in length for this to happen.	B1	
			at **Q** air molecules oscillate	B1	**allow** vibrate.
			with motion along the axis of the tube **or** with maximum amplitude.	B1	
			at **P** no motion / nodal point.	B1	
			Total	**12**	
22			**Level 3 (5−6 marks)** Clear explanation of observations **and** correct determination of frequency. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and*	**B1 ×6**	**Indicative scientific points may include:** Explanation of observations • Metal sheet reflects microwaves • Idea/description of superposition • Constructive/destructive interference • Standing wave pattern between T and plate • Maxima are antinodes and and minima are nodes. • Phase difference at nodes and antinodes • Distance between successive maxima/minima is $\lambda/2$ • Distance between adjacent regions of maximum and minimum intensities is $\lambda/4$

			substantiated. **Level 2 (3−4 marks)** Clear explanation of observations **or** correct method to determine the frequency **or** some explanation of observations and some method for the determination of the frequency *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* Level 1 (1−2 marks) Has limited explanation of observations **or** limited evidence of method to determine the frequency *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.		Determination of frequency • $f = \frac{v}{\lambda}$ • λ = 4 × 72 mm = 288 mm • $f = \frac{3\times10^8}{288\times10^{-3}} = 1.04 \times 10^9 \text{Hz}$ **<u>Examiner's Comments</u>** This was the second Level of Response question; a good range of marks was achieved. It required candidates to explain a standing wave pattern formed by microwaves. Many good candidates explained the pattern produced in terms of the metal sheet reflecting the microwaves, causing superposition with an explanation of nodes and antinodes. It was hoped that their understanding that the distance between successive maxima/minima is $\lambda/2$ would assist them in the calculation of the frequency. Good candidates wrote the equation and indicated that the wavelength of the microwaves was 0.288 m. Candidates should practise writing explanations to physics phenomenon. It is expected that the answers to these Level of Response questions will have a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated. **Exemplar 7**

					A stationary wave is formed when the incident and reflected microwaves superpose to form a resultant wave ~~consists~~ ~~consist~~. The resultant wave has maximum and minumum. The maximum represents an antinode. An antinode is formed when constructive interference takes place and similarly ~~da~~ a minimum (node) is formed where destructive interference takes place. ∴ The distance between an antinode and a node is 0.072 m, which is quarter of the wave length. The full wavelength is 0.288 m long (0.072×4). ∴ $v = f\lambda$ ∴ ~~velocity~~ frequency = $\frac{\text{velocity}}{\text{wavelength}}$ $f = \frac{3 \times 10^8}{0.288} = 1.0416 \times 10^9$ Hz $f = 1.04 \times 10^9$ Hz L3 This is an example of a Level of Response answer. The question gives a practical demonstration which candidates may have seen during the AS course. The question gives candidates the opportunity to describe the observations using their knowledge and understanding as well as determining the frequency of the microwaves. Candidates should use appropriate physics terms. In this case the candidate begins by implying that the microwaves are reflected by the barrier to superimpose a resultant wave. The candidate states that maxima are antinodes and formed by constructive interference. The candidate then explains the formation of nodes in terms of destructive interference. Appropriate physics terms have been used. The candidate has then correctly realised that the distance between the node and an anti-node is a quarter of a wavelength. The candidate could have stated that the distance between successive nodes is half a wavelength, but this is implied in the previous statement. Finally, the candidate clearly shows the method of determining the wavelength by quoting the wave equation, rearranging the equation and substituting values. The candidate finishes the determination of the frequency by calculating the frequency and then rounding to an appropriate number of significant figures two or three) and gives a correct unit (Hz).
			Total	**6**	
23			**Level 3 (5 – 6 marks)** Clear description and explanation for **both** experiments **and** some	**B1 × 6**	**Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc.** **Indicative scientific points may include:**

			discussion of uncertainty *There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear relevant and substantiated.* **Level 2 (3 – 4 marks)** Some description and explanation for **both** experiments **or** clear description and explanation for **one** experiment **and** some discussion of uncertainty *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited description and explanation for **one** experiment *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		**Description and explanation** **Experiment (a)** • Coherent signals / (sound) waves • Interference / superposition • Maximum signal / minimum signal • Idea of how wavelength is determined (e.g. distance between adjacent max positions = λ) • v = f × λ **Experiment (b)** • Stationary / standing wave produced • Superposition of waves travelling in opposite directions • Nodes / antinodes • Idea of how wavelength is determined (e.g. distance between adjacent nodes = $\lambda/2$) • v = f × λ **Uncertainty** • Measure multiples of λ • to reduce % uncertainty (by factor n) • move from minimum signal to minimum signal • so can increase sensitivity of scope to get better fix on each minimum position / increase loudness from speaker • Lower frequency from signal generator • so increases A with (%) uncertainty reduced • Do experiment outside • to reduce background reflections from room (so that sharper minima should be observed) **Examiner's Comments** Answers were generally well structured into two sections, one for each experiment. A few candidates thought they could measure the wavelength on the oscilloscope screen. In experiment (a) most understood that the phase difference between the two oscillations at the microphone changed as one speaker was moved away. Explanations often muddled *path* and *phase* difference or referred to *nodes* and *antinodes* detected by the microphone. Some candidates misinterpreted the experiment moving the microphone to detect interference fringes, allowing the double slits formula to be used to find the wavelength. Others thought that Doppler shift was applicable. For experiment (b) many candidates used *maxima* and *minima* in place of *antinodes* and *nodes* although most recognised this to be a *standing* wave situation. Quite a few candidates ignored the instruction about reducing the uncertainty. The best candidates suggested reducing the frequency to reduce the percentage uncertainty in the wavelength measurement.

			Total	6	
24			**Level 3 (5–6 marks)** Clear explanation of observations **and** correct method to determine the speed of sound *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear explanation of observations **or** correct method to determine the speed of sound **or** has limited explanation of observations and limited method for the determination of the speed of sound *There is a line of reasoning presented with some structure. The information presented is in the mostpart relevant and supported by some evidence.* **Level 1 (1–2 marks)** Has limited explanation of observations **or** limited evidence of method to determine the speed of sound *The information is basic and communicated in an unstructured way.*	**B1 x6**	**Indicative scientific points may include:** **Explanation of Observations** • Understanding of how the standing wave is formed from the interference between the incident and reflected wave • Idea of nodes and antinodes • Node at closed end and antinode at open end • Understanding of the direction of oscillation of particles • Fundamental frequency/1st harmonic indicated for closed tube. • Fundamental frequency/1st harmonic indicated for open tube • Harmonics indicated for closed tube • Harmonics indicated for open tube **Determination of speed of sound** • λ correctly linked to length • $v = f\lambda$ • v calculated for different harmonics / tube or appropriate graphical method • 338 ms^{-1} **Examiner's Comments** The second level of response question required candidates to explain the results of an experiment investigating stationary waves in a closed and open hollow tubes. Good candidates demonstrated their knowledge and understanding by explaining how the standing wave was formed, where nodes and antinodes were positioned and how the wavelength of the stationary wave could be determined. Many candidates drew additional diagrams showing the harmonics in both open and closed tubes. To gain the highest marks, it was expected that candidates would determine the speed of sound correctly for more than one tube.

			The information is supported by limited evidence and the relationship to the evidence may not be clear. **0 marks** No response or no response worthy of credit.		
			Total	**6**	
25			***Level 3 (5–6 marks)** Clear explanation and analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation and some analysis. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation **or** limited analysis *The information is basic and communicated in an unstructured way. The information is supported by limited evidence*	B1 × 6	**Indicative scientific points may include:** **Explanation** • Sound reflected at closed end • Superposition / interference produces stationary wave within tube • Maximum identified as anti-nodes • Minima identified as nodes **Analysis** • $\lambda/2 = 0.26$ (m) or $\lambda = 0.52$ (m) • period = 1.5 (ms) • frequency = 1/0.0015 or frequency = 660 (Hz) • $v = 0.52 \times 660 = 340$ m s^{-1} (**Note**: $v = 350$ m s^{-1} if there is no rounding.)

			and the relationship to the evidence may not be clear. **0 marks** No response or no response worthy of credit.		
			Total	**6**	
26	a	i	a = (−) $4\pi^2 f^2 x$ = 4 × 9.87 × 4900 × 0.004	C1	**allow** 774 (m s^{-2})
		i	a = 770 (m s^{-2})	A1	
		ii	**1** sketch showing one wavelength and 140 (Hz)	B1	both sketch and value required for 1 mark
		ii	**2** driving force is around nodal point / AW;	B1	**max** 3 of the 4 marking points
		ii	points either side of nodal point try to move in opposite directions when force in one direction / AW;	B1	
		ii	move magnet to antinodal point; ¼ of distance between clamps	B1	**not** increase current
	b	i	*f α* √T so f = 70/√2 = 49 or 50 Hz	B1	
		ii	**1** μ increases / goes up by 0.4%	B1	**allow** +0.4% NOT 0.4%
		ii	**2** 0.2%,	B1	**or** half of answer to **(ii)1**
		ii	f is lower because μ is bigger and μ is on the bottom of the formula	B1	**or** greater inertia present with same restoring force / other physical argument
			Total	**10**	
27		i	Straight-line of best fit drawn gradient = 170 (Hz m)	B1 B1	**Allow** value in range 160.0 to 180.0 **<u>Examiner's Comments</u>** The straight-lines of best fit were generally acceptable. A small number of candidates drew the lines using very thick or indistinct pencil leads. Large triangles were often used to determine the gradient of the lines. Only a very

					small number of candidates, mainly at the lower quartile, made errors with powers of ten and got an answer of 0.17 instead of 170.
		ii	$v = f\lambda$ or $\lambda = 2L$ **or** $v = 2fL$ (Any subject) Clear steps leading to gradient $= \frac{v}{2}$ using $y = mx$	C1 A1	Allow separation between adjacent nodes $= \frac{\lambda}{2}$ **Allow** gradient = $f \div (\lambda/2)^{-1} = f\lambda/2 = v/2$ **<u>Examiner's Comments</u>** Most candidates scored 1 mark for either quoting the wave equation v = fλ or the wavelength being twice inter-nodal distance *L*. The analysis leading to the gradient = *v*/2 proved to be quite demanding for most of the candidates. The most frequent incorrect reasoning was that speed v was divided by 2 because the sound waves are reflected from the wall, and they had to travel twice the distance there and back. Only the most able of the candidates scored full marks.
		iii	$v = 2 \times 170$ v = 340 (m s^{-1})	B1	Possible ECF from **(b)(i)** **<u>Examiner's Comments</u>** Almost all candidates picked up 1 mark for multiplying their answer from **(b)(i)** by 2. This included those who also got an answer such as 0.17 in (b)(i). Error carried forward (ECF) rules were applied even when the speed of sound looked unrealistic.
		iv	Decrease frequency / f (ORA) L / λ increases (so, smaller % uncertainty) (ORA) **or** Measure distance between several nodes / antinodes Distance measured is larger (so, smaller % uncertainty) **or** Use a small(er) microphone Easier to locate position of node / antinode (so,	M1 A1 M1 A1 M1 A1	**Allow** other sensible suggestions **Allow** increase wavelength / λ (ORA) **Allow** L increases (so, smaller % uncertainty) (ORA) **Allow** reduce reflection of sound (other than from the wall) **<u>Examiner's Comments</u>** This was a low-scoring question, with many candidates focussing on averaging results. Only a small number of candidates appreciated that lower frequency would give longer inter-nodal distance L, and this resulted in smaller percentage uncertainty.

			smaller % uncertainty)		
			Total	**7**	
28			**Level 3 (5 – 6 marks)** Response shows clear distinction between investigations; clear and correct reasoning is given for the situations which give maximum / minimum readings in <u>both</u> cases, including correct numerical values *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3 – 4 marks)** Response refers to both investigations; some reasoning is given for the situations which give maximum / minimum readings in <u>both</u> investigations, including some numerical values *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited reasons are given for the	B1 x 6	**Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2ˆ for 3 marks, etc.** **Indicative scientific points may include:** **explanation 1** • receiver aerial vertical – electrons are driven (maximum distance) up and down along the length of the aerial because the oscillations (of the electric field) are vertical, causing maximum (a.c.) current • receiver aerial horizontal – electrons are driven (minimum distance) across the aerial because the oscillations (of the electric field) are only in the vertical plane (no oscillation along the aerial to cause current), so zero / minimum current • rotation of receiver aerial by ± 90° (or 90° and 270°) from vertical leads to zero current **explanation 2** • reflected wave superposes with incident wave at receiver aerial • coherent waves as from same source • constructive interference / waves in phase gives max current • reflected wave has travelled nλ further, n = 0,1, etc • so max current when plate is at λ/2, 2λ/2, etc from receiver aerial, i.e. 30, 60 cm • destructive interference / waves 180° (π rad) out of phase gives zero current • reflected wave has travelled (2n +1)λ/2 further, n = 0,1, etc • so zero current when plate is at λ/4, 3λ/4, etc from receiver aerial, i.e. 15, 45 cm • reflected signal will be weaker the further it has to travel so no longer complete cancellation (ammeter reads close to zero) **Note:** Give full credit to candidates who take the 180° (π rad) phase change on reflection into account, which gives max current at 15, 45 cm etc and zero current at 30, 60 cm etc. **<u>Examiner's Comments</u>** This was the second of the two LoR questions in this paper. It required knowledge of polarisation, superposition and interference. There is no one perfect model response but generally, for Level 3, candidates were required to give clear reasoning for the situations which gave both maximum and minimum readings in both investigations. Such candidates included correct numerical values in their responses (although 'half a wavelength' was acceptable in place of 30cm). Level 2 responses were sometimes incomplete (e.g. giving the maximum position but not the minimum position) or confused (e.g. the maximum and minimum positions were given but were the wrong way around). Level 1 responses came from candidates who misunderstood the physics of one of the situations, or who confused phase difference and path difference, or whose descriptions were generally too vague to gain much credit.

			situations which give maximum / minimum readings in <u>either</u> investigation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		It may be helpful to point out that investigation **2** was not about the formation of a stationary wave; rather, it was about two overlapping coherent waves forming regions of constructive and destructive interference. A common misconception was that the maximum and minima signals were related to antinodes and nodes. **Misconception** A minimum or zero reading does not occur when two waves are merely out of phase. They must be *completely* out of phase. The best way to describe this is to say that they are **in antiphase**.
			Total	**6**	
29		i	reflected signals from M (amplitude a) and H (amplitude A) are added at the receiver	B1	**accept** interfere.
		i	path difference between moving reflected signal and fixed reflected signal varies between 0 and λ	B1	**or** phase difference between the two received signals varies between 0 and 2π
		i	sum of the displacements at the receiver varies between A + a and A – a	B1	
		i	any 3 from • signal from M is attenuated because travels further; • absorbed passing twice through H or some reflected at the back of H • signal from H will	B1	allow absorbed or similar word for attenuated.

			increase as H moves towards the detector • if A is much greater than a then variation will be difficult to detect.		
		i			allow full credit for discussion in terms of $(A^2 - a^2)/(A^2 + a^2)$.
		ii	detected signal varies between max and min for λ/4(= 7.0 mm) as path difference is λ/2	B1	
		ii	every λ/2 (14 mm) moved, the signal goes through one cycle	B1	
		ii	so for 200 Hz must go through 100 λ in 1 s = 2.8 (m s^{-1}).	B1	
			Total	**9**	