Mark scheme – Wave Superposition

Question			Answer/Indicative content	Marks	Guidance
1			Constant phase difference (between two or more waves)	B1	**Ignore** in phase
			Total	**1**	
2			A	1	
			Total	**1**	
3			(At the point where two or more waves meet the) resultant displacement is equal to the sum of the individual displacements (of the waves)	B1	**Allow** sum / net / total for resultant **Ignore** vector sum **Not** amplitude
			Total	**1**	
4	a		constant phase (difference of 90°)	B1	**Ignore** incorrect value **Ignore** same wavelength / frequency / period
	b		(period =) 4.0 (ms) (f = 0.004^{-1}) f = 250 (Hz)	C1 A1	**Allow** 1 mark for 0.25; k omitted
	c		(intensity =) $\left(\frac{24}{10}\right)^2 (I_0)$ intensity = 5.8 (I_0)	C1 A1	**Not** $\frac{144}{25} I_0$ **Allow** 1 mark for 4.84; misread graph and used $(\frac{22}{10})^2$
	d		resultant displacement = 10 (μm)	B1	**Allow** ± 1.5; **Ignore** sign
			Total	**6**	
5			There is a constant phase difference between the waves.	B1	
			Total	**1**	
6			Waves / sources with constant phase difference.	B1	
			Total	**1**	
7			(When two or more waves meet at a point) the resultant displacement is (equal to) the sum of the (individual) displacements (of the waves)	B1	**Allow** sum / total / net for resultant **Ignore** vector sum
			Total	**1**	
8			**C**	1	

			Total	**1**	
9			**A**	**1**	
			Total	**1**	
10			c	1	**Examiner's Comments** This question was assessing knowledge and understanding of path difference and constructive interference. The path difference is 4.0 m. With the waves in phase at **X** and **Y**, this means that the distance of 4.0 m must be equal to a multiple of wavelengths. This condition is satisfied by all but **C**. You cannot get 4.0 m by multiplying 3.0 m by an integer. The majority of the candidates effortlessly picked up 1 mark here.
			Total	**1**	
11			C	1	**Examiner's Comments** The correct response is **C**. Although not a particularly challenging question, it was encouraging to see around three quarters of entrants getting the correct solution. The most common incorrect response was **A**, suggesting that the idea of time period is not necessarily well understood.
			Total	**1**	
12			A	1	**Examiner's Comments** The correct response is **A**. A good number of candidates were able to correctly identify the new fringe separation. Most correctly identified the appropriate equation from the booklet and set out the solution either as ratios or by direct calculation. Quite a large fraction who achieved the correct response showed no working, suggesting that this is a relatively simple calculation probably done directly into a calculator.
			Total	**1**	
13			A	1	**Examiner's Comments** The correct response is **A**. This question was correctly answered by the vast majority of candidates, who were able to select the correct terms applicable.
			Total	**1**	
14			**B**	1	
			Total	**1**	
15			**D**	1	
			Total	**1**	
16	a		(When two or more waves meet at a point in space) the resultant (displacement) is	**B1**	**Allow** total / Σ / net for resultant **Not** amplitude for displacement

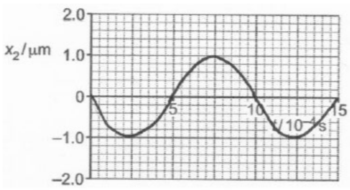
			equal to the (vector) sum of the individual <u>displacements</u> of waves (meeting at a point)		**Examiner's Comment** Most candidates made a poor start to Section B by incorrectly stating the principle of superposition. Instead of *'the resultant displacement being the sum of the individual displacements of the waves'*, candidates wrote about the addition of **amplitudes.** Some simply wrote about constructive (or destructive) interference and stationary waves.
	b	i	Clear evidence of at least two fringe separations used to determine x **and** x in the range 7.0 to 9.0 mm $\lambda = \frac{0.25\times10^{-3}\times8\times10^{-3}}{4.25}$ (Allow any subject) $A = 4.7 \times 10^{-7}$ (m)	**B1** **C1** **A1**	**Expect** 8 (mm) **Allow** ecf for incorrect value of x **Examiner's Comment** One mark for this question was reserved for accurately determining the separation x between adjacent fringes using at least two fringe separations. About a quarter of the candidates did this and secured maximum marks for calculating the wavelength of blue light. A wide range of 7 mm to 9 mm was allowed for x. Most candidates used the correct equation and had no problems with powers of ten. Almost all the answers were written in standard form.
		ii	Red light has longer wavelength / λ **and** separation between fringes increases (AW) Separation between fringes justified in terms of $x \propto \lambda$ or $x = \lambda D / a$, D <u>and</u> a are constants	**M1** **A1**	**Allow** other acceptable labels for D and a **Examiner's Comment** This was generally well answered with most candidates giving correct explanation of why the fringe pattern was more spread out. Many candidates wrote concise answers such as 'the *fringe separation increases because red light has longer wavelength and fringe separation x wavelength'*. The two most common errors were: • Red light has shorter wavelength than blue light. • The pattern had something to do with the refraction of light through the double-slit.
			Total	**6**	
17			The net amplitude is non-zero.	B1	
			Destructive interference occurs.	B1	
			Total	**2**	

18			*phase difference:* difference in degrees / radians/angle between points on the same wave or (similar) points on two waves *coherence:* constant / fixed phase difference	**B1** **B1**	**Note** must be a comparison between points / waves **Allow** how far out of step / sync or leads / lags for difference **Allow** constant / fixed phase relationship **Ignore** 'the frequency / wavelength is the same' **Not** the same phase difference **Not** zero phase difference **Examiner's Comments** Many candidates found it difficult to define phase difference although coherence was usually correctly defined.
			Total	**2**	
19			Maxima is when <u>constructive</u> (interference) occurs / phase difference is zero / path difference = $n\lambda$ Minima is when <u>destructive</u> (interference) occurs / phase difference is 180(°) or π(rad) / path difference = $(n + ½)\lambda$ at minima	B1 B1	**Allow** 'completely in phase' for phase difference is zero **Allow** 'antiphase'/ 'completely out of phase' for phase difference is 180(°) **Allow** 1 mark for 'constructive and destructive (interference)', without any link to the maxima and minima
			Total	**2**	
20			Waves are reflected at the pulley end.	B1	
			This produces nodes and antinodes on the string.	B1	
			Total	**2**	
21			Interference / superposition (of microwaves along **PQ**) Maximum (signal) / constructive (interference) when waves are in phase Minimum (signal) / destructive (interference) when waves are in anti-phase	**B1** **B1** **B1**	**Allow** constructive when <u>phase</u> difference is n × 360° (n is an integer) / 0° / 360° **Allow** destructive <u>phase</u> difference is [2n + 1] × 180° (n is an integer) / 180° **Not** 'out of phase' **Special case** - allow 1 mark from the last two B1 marks, for signal linked to <u>path</u> difference and wavelength **<u>Examiner's Comments</u>** Many candidates made a start by defining coherence, this was not necessary. Most candidates realised that the maximum and minimum signals were linked to superposition, or interference, of

					the waves from **A** and **B**. The majority of the candidates equated coherence with 'in phase' and gave explanations in terms of **path** difference instead of **phase** difference. Constructive interference could not be linked to an integer number of wavelengths but it could be linked to the waves being **in phase**. Similarly, for destructive interference, the apt explanation was that the waves are in **anti-phase** at points of minimum signal. Specific values of phase differences were allowed. For anti-phase, '**completely** out of phase' was allowed. Some of the common misconceptions were: • The maximum and minima signals were related to antinodes and nodes • The variation in the signal was due to Doppler effect
			Total	**3**	
22	a		Select $\lambda = ax / D$ and x = 6.0 × 10^{-3}/5 = 1.2 × 10^{-3} m	C1	
			$\lambda = 0.8 \times 10^{-3} \times 1.2 \times 10^{-3} / 1.6$	C1	
			λ = 600 (nm)	A1	**Allow** 2 marks for 500 nm
	b		*Please refer to point 10 of the marking instructions of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Expect all points to be addressed, coherence or means of achieving this, all experimental measurements, and an identification of the greatest uncertainty consistent with the methodology described. *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)** Sufficient detail is given to demonstrate an understanding of the execution of the experiment and taking measurements of different orders of magnitude. Reference is made, with limited reasoning to uncertainty. Some detail may be omitted. *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)**	B1	**Indicative scientific points may include** **Coherence (C)** 1. Light from slits must be coherent / have constant phase relationship 2. use narrow slit close to lamp or lens to focus beam 3. diffract 'same' light through both slits **Experiment (E)** 1. $S1S_2$: vernier caliper or micrometer, travelling microscope, projected image with known lens 2. AB : vernier caliper, calipers, mm rule (magnifying glass) 3. D from slits to screen : ruler or tape measure with mm markings **Uncertainty (U)** 1. $S1S_2$: 0.1 mm in 0.8 mm with travelling microscope,vernier or micrometer, 2. AB on screen : 0.1 mm in 6 mm with travelling microscope or vernier, 1mm in 6mm with rule 3. D from slits to screen: 1 mm in 1.6.m so very small uncertainty **Conclusion** Expected answer S_1S_2, 12.5% uncertainty

			Basic information on equipment and measurements or measurements and uncertainty are given. *The information is basic and communicated in an unstructured way. 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.		Alternatives based on equipment selected should be credited: AB on screen with ruler giving 16.7% uncertainty
	c		percentage uncertainty in *a* decreases	B1	**Allow** any argument qualitative or quantitative, which considers: effect on a, effect on x and correct conclusion
			fringes move closer together / percentage uncertainty in *x* increases / actually measuring 5*x* so smaller effect / **AW**	B1	Allow alternative arguments, e.g. D is easily increased increasing *x* so increase in a will decrease uncertainty in *λ* as *Δa / a* smaller
			with both measurements to 0.1 mm, measurement of *a* gives larger improvement so decrease in uncertainty in *λ*	B1	
			Total	**12**	
23			(x =) 200 × 18 **or** (x =) 3600 (m) $(\lambda =) \frac{120 \times 3600}{2400}$ *λ* = 180 (m)	C1 C1 A1	**Not** $v = f\lambda$; $18 = \frac{1}{200} \times \lambda$ **or** λ = 3600 (m) **Allow** 3600 m from $v = f\lambda$ when used as x here **Note** using x = 1800 m is **XP** (this gives 90 m)
			Total	**3**	
24		i	The superposition of coherent waves	**B1**	**Not** 'combine / meet / interact' for 'superposition' **Allow** 'superposition of waves with a constant phase difference (at the sources)' **Allow** 'waves that superpose constructively / destructively' **Examiner's Comments** Most candidates gave vague answers for interference. Answers such as '*this is when waves interact or collide*' were prevalent. Interference is the superposition of coherent waves.
		ii	path difference (is 4.5 cm, which) is 1.5*λ* Destructive interference occurs	**M1** **A1**	**Allow** lengths are 5λ & 3.5λ **and** phase difference = 180$^{(o)}$ or waves are in anti-phase **Not** λ/2 out of phase **Not** path difference is 1.5 cycles / periods / oscillations **Examiner's Comments** This was another question that favoured the top-end candidates. The question required a clear understanding of path difference. Credit could only be given if the distances of 10.5 cm and 15.0 cm were used to answer the question. Destructive interference

					occurred at **C** because the path difference is **1.5**λ. A significant number of candidates struggled to get their physics across. Path difference was confused with phase difference and *'cycles'* was used to imply wavelength. Many candidates incorrectly concluded that the path difference was **0.5**λ. Weaker candidates referred to *nodes* and *antinodes* in their descriptions.
			Total	**3**	
25		i	0.08 (m)	A1	
		ii	π (rad)	A1	
		iii	path difference = λ/2 or 2 × 0.08 0.16 (m)	M1 A0	**Allow ECF** from **(b)(i)** **Allow** path difference shown at K
			Total	**3**	
26			Quieter than average (and / or louder) Regions of destructive interference (and / or constructive interference) Calculation of fringe spacing (x = 330×30/(1200×5.0) = 1.65 m) Effect is less noticeable further from the centre owing to different amplitudes received from each speaker	B1 B1 B1 B1	AW
			Total	**4**	
27		i	Bright fringes are due to constructive interference and the dark fringes are due to destructive interference.	B1	
		i	Path difference is $n\lambda$ **or** phase difference is 0° at positions of bright fringes.	B1	
		i	Path difference is $(n + \frac{1}{2})\lambda$ **or** phase difference is 180° at positions of dark fringes.	B1	
		ii	**A** emits shorter wavelength of light. Since $x = \frac{\lambda D}{a} \propto \lambda$, the separation between the adjacent fringes is smaller.	B1	
		iii	There is no interference of light from the two slits **or** the bands disappear **or** there is only diffraction from a single slit.	B1	
			Total	**5**	

28		i	Correct curve with amplitude of 1.0 μm and a phase difference of 180°  	**B1**	**Allow** a curve shown for a minimum of one period **Allow** ± 0.2 μm for amplitude at any two points **Not** 'triangular' profile for the curve
		ii	The amplitude (at **P**) is smaller / < 3.0 (<m) / = 2.0 (<m) intensity ∝ amplitude^2 (therefore the intensity is not the same)	**B1** **B1**	**Not** displacement **Allow** $I \propto A^2$, where I = intensity and A = amplitude **Allow** 2 marks for 'intensity is $\left(\frac{2}{3}\right)^2 \times 100 = 44\%$
		iii	(The path difference is) 17 (cm) **or** half wavelength **or** λ/2. Hence destructive (interference)	**M1** **A1**	**Not** $(n + ½)\lambda$ **Not** <u>phase</u> difference is 17 (cm) **or** half wavelength **or** λ/2 **<u>Examiner's Comments</u>** In **(b)(i)**, the majority of the candidates drew the correct curve of amplitude 1.0 μm and a phase difference of 180°. Many candidates in **(b)(ii)** did not mention intensity at all in their description. Instead, the focus was on destructive interference without reference to their answer in **(b)(i)**. A very small proportion of candidates did realise that the smaller amplitude of the signal at P meant the intensity was reduced because intensity is directly proportional to amplitude^2. **(b)(iii)** was demanding. It was only the top–end candidates realising that the path difference of half a wavelength (17 cm) meant that the interference was destructive at point **Q**. Too many answers did not make any use of the information given in the question. Generic comments on interference prevented marks being gained in this question.
			Total	**5**	
29		i	phase difference = n × 360(°) for bright (fringes) / constructive (interference) phase difference = (n + ½) × 360(°) for dark (fringes) / destructive (interference)	B1 B1	**Allow** zero **or** n × 2π(rad) **or** even number of π (rad) **or** even number of 180(°) **Allow** 180(°) **or** (n + ½) × 2π(rad) **or** odd number of π (rad) **or** odd number of 180(°) **Special case:** 1 mark for 'completely in phase for bright fringes / constructive (interference) and in anti-phase / completely out of phase for dark fringes / destructive (interference)'
		ii	$\lambda = \frac{3.0 \times 10^{8}}{4.75 \times 10^{14}}$ **or** $\lambda = 6.316 \times 10^{-7}$ (m)	C1 C1	

			$x = \frac{6.316 \times 10^{-7} \times 8.2}{0.20 \times 10^{-3}}$ **or** x = 0.0259 (m) t = 0.14 (s)	A1	**Note** the answer must be given to 2 SF for this mark **Special case:** allow 1 mark for 8.6 × 10^{-11} s on the answer line; incorrect physics using 0.18 = 4.75 × 10^{14} λ
			Total	**5**	
3 0			**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 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.*	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. 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**	
3 1		i	(speed in material =) $\frac{3.0 \times 10^8}{1.20}$ **or** 2.5×10^8 (ms^{-1}) (t_V =) $\frac{1.5 \times 10^{-6}}{3.0 \times 10^8}$ **or** 5.0×10^{-15} (s) (t_M =) $\frac{1.5 \times 10^{-6} \times 1.20}{3.0 \times 10^8}$ **or** 6.0×10^{-15} (s) $t = [6.0 - 5.0] \times 10^{-15} = 1.0 \times 10^{-15}$ (s)	C1 C1 C1 A0	**Allow other correct methods** **Note** omitting or incorrect use of 1.2 is XP **Allow** 1 SF answer 5×10^{-15} **Allow** 1 SF answer 6×10^{-15} **Note** this also scores the first C1 mark **Note** omitting or incorrect use of 1.2 is XP **<u>Examiner’s Comments</u>** Generally, candidates answered this question extremely well and most scoring full marks In **(c)(i)**, the solutions ranged from being well-structured to an assortment of equations and substitutions filling the entire answer space. Equations for refractive index and speed were easily used to show the answer to be 1.0×10^{-15} s. In **(c)(ii)**, candidates either calculated the frequency of 5.0×10^{14} Hz and then used $T = f^{-1}$ or calculated T directly using $T = \frac{6.0 \times 10^{-7}}{3.0 \times 10^8}$ $= 2.0 \times 10^{-15}$ s. **(c)(iii)** provided some discrimination with middle and top candidates getting the correct answer of 180°. As always, error carried forward (ECF) rules apply in calculations. This helped

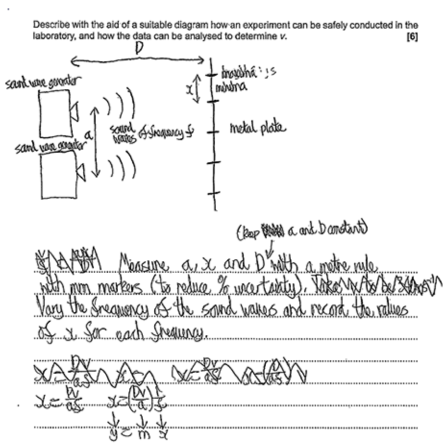
					those candidates who got an incorrect answer of 2.4×10^{-15} s in **(c)(ii)** to score a mark for 150°. **Misconception** There were some missed opportunities, with some candidates making the following mistakes. • In **(c)(i)** calculating the difference in the time for the two rays by halving the period of 2.0×10^{-15} s. • In **(c)(ii)** using the wavelength in vacuum of 6.0×10^{-7} m but the incorrect speed of 2.5×10^{8} ms^{-1} to calculate the period. This gave an answer of 2.4×10^{-15} s; examiners allowed 1 mark for this method. • In **(c)(iii)**, a small number of candidates, mainly at the low-end, confused the symbol φ for phase difference to be work function. This produced some bizarre answers.
		ii	$(f =) \frac{3.0\times10^{8}}{6.0\times10^{-7}}$ **or** 5.0×10^{14} (Hz) **or** $(T =) \frac{6.0\times10^{-7}}{3.0\times10^{8}}$ $T = 2.0 \times 10^{-15}$ (s)	C1 A1	**Allow** 1 SF of 2×10^{-15} **Allow** 1 mark for 2.4×10^{-15} (s); 2.5×10^{8} ms^{-1} used
		iii	$\varphi = 180°$	B1	Possible ECF from **(i)** and **(ii)** **Note** answer must be φ = **(c)(i)** × 360°/**(c)(ii)** **Not** an answer in rad, e.g. π rad
			Total	**6**	
32			**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 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*	**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 $\lambda/4$ Determination of frequency • $f = \frac{v}{\lambda}$

			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.		• λ = 4 × 72 mm = 288 mm • $f = \frac{3\times10^8}{288\times10^{-3}} = 1.04\times10^9\text{Hz}$ **<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 *λ/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 and reflected microwaves superpose to form resultant wave ~~exacts~~ ~~consist~~ The resu wave has maximum and minimum Th maximum represents an antinode. An an is formed when constructive interference takes and similarly ~~da~~ a minimum (node) is formed destructive interference takes place. ~~w~~ Th distance between an antinode and is 0.072m, which is quarter of the wa The full wavelength is 0.288 m long (0.072×4) ∴ v=fλ ∴ ~~velocity~~ frequency = velocity / wavelength $f = \frac{3\times10^8}{0.288} = 1.0416$ $f = 1.04\times10^9$ Hz

					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**	
3 3		i	0.45 (m)	B1	**Examiner's Comments** This question was generally answered very well. Most candidates understood the definition of amplitude although, a number of candidates incorrectly stated 0.9 m
		ii	4.0 (m)	B1	**Ignore** significant figures **Examiner's Comments** This question was generally answered very well with most candidates understanding the definition of wavelength.
		ii i	$\frac{0.5}{4}$ or $\frac{1}{8}$ $(\frac{0.5}{4} \times 2\pi =) \frac{\pi}{4}$ or 0.79 (rad)	C1 A1	**Allow ECF** from (ii) **Note** 0.785 **Examiner's Comments** The majority of candidates did not gain credit on this question. Successful candidates clearly showed their working. Some

					candidates were not sure how to change a fraction of a wavelength into a phase difference in radians.
		iv	0.45^2 or 0.15^2 or 0.2025 or 0.0225 9	C1 A1	**Allow ECF** from (i) **Allow** one significant figure **<u>Examiner's Comments</u>** Candidates found this question challenging. They often did not realise that the intensity is proportional to the amplitude squared. It was helpful where candidates showed their working.
			Total	**6**	
34			**Level 3 (5–6 marks)** Clear methods of measurement, statement of uncertainties **and** how to minimise them *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)** Adequate methods of measurement, statement of uncertainties **and** how to minimise them *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 methods of measurement, statement of uncertainties **or** how to minimise them *The information is basic and communicated in an unstructured way. 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.	B1 × 6	**Indicative scientific points may include:** **M measurement** **D** measured with metre rulers **y** measured using mm graticule on glass screen observed with hand lens **U uncertainty** **D** maximum ±2 mm in 1.5 to 2.0 m 0.1% **y** ±0.5 mm in the position of the centre of each maximum, giving an uncertainty of ±1 mm $\times = 600 \times 10^{-9} \times 2/5 \times 10^{-4} = 2.4$ mm so we have y = 5x with ±1/(2.4 × 5) so of order of 8 to 10% in value of x. **a** vernier to ±0.05 mm in 0.5 mm gives uncertainty of order of 10% **total** uncertainty of about 20% or ± 100 nm to 120 nm **A minimising uncertainties** **D** maximise distance available on bench **y** measuring across the maximum number of x possible **a** suggesting that a more sensitive method is needed, e.g. using slide projector to display enlarged image of slits on screen compared to millimetre scale projected on screen or similar
			Total	**6**	
35			**Level 3 (5–6 marks)** Clear procedure, measurements and analysis *There is a well-developed line of reasoning which is clear **and** logically structured. The*	B1 x 6	**Indicative scientific points may include:** **Procedure** • labelled diagram • two loudspeakers OR loudspeaker and double slit • signal generator connected to loudspeaker(s)

			information presented is relevant and substantiated. **Level 2 (3–4 marks)** Some procedure, some measurements **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 procedure, limited measurements **and** limited analysis *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.		• microphone and oscilloscope/sound sensor • microphone and oscilloscope/sound sensor moved between loudspeakers • safety precaution (ear defenders) • method to avoid reflections of sound • change frequency and repeat measurements for x • $D >> a$ **Measurements** • frequency determined from oscilloscope/ reading from signal generator • additional detail from use of oscilloscope e.g. time-base to determine period and $f = 1/T$ • use of rule(r) to measure distances *a, D* and *x* • measures over several maxima/minima **Analysis** • rearrangement of equation for v or into $y=mx$ • plot a graph of x against $1/f$ or equivalent • straight line through origin confirms relationship • gradient = vD / a • $v = \frac{a \times \text{gradient}}{D}$. **<u>Examiner's Comments</u>** This question is assessing candidates' abilities to plan an investigation. Some candidates assumed that this was two-source light interference and discussed the use of lasers, etc. It is important that candidates answer the question set. The stem of the question indicates that a suitable diagram should be drawn. Many candidates did not label their diagrams, or the diagrams were not workable. Higher ability candidates indicated two loudspeakers connected to a signal generator and a microphone connected to an oscilloscope to detect the resultant signal. When answering planning questions, candidates should identify the measurements that need to be taken and indicate appropriate measuring instruments. In this experiment, candidates were able to explain how the frequency of the sound could be determined using an oscilloscope as well as how distances could be measured. Candidates also needed to explain how the data would be analysed. Higher ability candidates suggested the plotting of an appropriate graph and explained how the speed of sound could be determined from the gradient.

					AfL Practical skills guidance can be found in the Practical Skills Handbook available on the OCR website: https:/www.ocr.org.uk/Images/295483-practical-skills-handbook.pdf **Exemplar 7**  The candidate's is answering the question as shown by the diagram containing two speakers. There is an indication of how the distances may be measured and that the frequency is going to be varied. The candidate also indicated how the results would be analysed graphically and how the speed of sound could be determined from the gradient of the plotted graph. This is a Level 2 response worth four marks since there is a line of reasoning and the information provided is relevant. To improve this response, the candidate could have included a signal generator and also a means of detecting the sound at the distance indicated. There should also have been detail on how the frequency was determined.
			Total	**6**	
3 6			**Level 3 (5 – 6 marks)** Clear description and explanation for **both** experiments **and** some discussion of uncertainty *There is a well-developed line of reasoning which is clear and logically structured. The*	**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:** **Description and explanation** **Experiment (a)**

			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.*		• Coherent signals / (sound) waves • Interference / superposition • Maximum signal / minimum signal • Idea of how wavelength is determined (e.g. distance between adjacent max positions = λ) • $v = f \times \lambda$ **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 = $\lambda/2$) • $v = f \times \lambda$ **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**	
37	a	i	At point P: path difference between slits and screen is a whole / integer number of	**B1**	**Allow** nλ or λ **Not** phase difference

			wavelengths (for constructive interference) At point Q: path difference between slits and screen is an odd number of half wavelengths (for destructive interference)	B1	**Allow** $(n+\frac{1}{2})\lambda$ **Not** $\lambda/2$ **Examiner's Comments** It was expected that candidates would describe the path difference in terms of the wavelength. Candidates often realised that the bright line would have a path difference of an integer number of wavelengths, this was often written as nλ. To explain the dark line many candidates struggled with the appropriate relationship in terms of λ or did not state an odd number of half wavelengths.
		ii	**1** x = 4.22 mm $\lambda = \frac{4.22 \times 10^{-3} \times 0.56 \times 10^{-3}}{4.50}$ 5.25 × 10^{-7} m $\frac{0.02}{4.5}$ or $\frac{0.02}{0.56}$ or $\frac{0.2}{42.2}$ $\left(\frac{0.02}{4.5}+\frac{0.02}{0.56}+\frac{0.2}{42.2}\right) \times 100 = 4.48\ \%$ Alternative max / min method: **2** $\lambda_{max} = \frac{4.24 \times 10^{-3} \times 0.58 \times 10^{-3}}{4.48} = 5.49 \times 1$ and/or $\lambda_{min} = \frac{4.20 \times 10^{-3} \times 0.54 \times 10^{-3}}{4.52} = 5.02 \times 1$ $\frac{\Delta\lambda}{\lambda} \times 100 = 4.4\%\ or\ 4.6\%$	C1 C1 A1 C1 A1 B1 B1	**Note x** = 42.2 mm or 4.2 × 10^{-2} m scores zero **Note x** = 3.84, 4.77 × 10^{-7} m may score max 2 **Allow** 4% or 5% with evidence of working **Ignore** significant figures **Examiner's Comments** Although candidates correctly identified the correct equation, a large number of candidates did not determine the fringe spacing correctly. Some candidates used 42.2 cm, others divided 42.2 cm by 11, 15 or 20. Furthermore, some candidates did not convert the slit separation from millimetres to metres. Candidates were able to identify the equation from the Data, Formulae and Relationships Booklet. Most candidates were able to determine at least one percentage uncertainty for the individual quantities correctly. Mistakes were made either on determining the other quantities or adding the percentage uncertainties. Some candidates attempted a maximum / minimum method – the common error with this method was not dividing maximum by minimum or minimum by maximum.
	b	i	$\frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{5.25 \text{ x } 10^{-7}} = \frac{1.989 \times 10^{-25}}{\mathbf{5\ b\ ii\ 1}} = 3.79$ $n = \frac{50 \times 10^{-3}}{3.79 \times 10^{-19}} = 2.5 \times 10^{23} \times \mathbf{5\ b\ ii\ 1} = 1.3 \times$	C1 A1	**Allow** ecf from **bii** **Examiner's Comments** Candidates found this question difficult. Many could not determine the energy of a photon correctly – an error carried forward was allowed from **5(b)(ii)1.** The question also required candidates to realise that 50.0 mW is equivalent to 50.0 mJ s^{-1}. A common error was to divide the power by the charge on an electron.

		ii	2.6 eV = 2.6 × 1.6 × 10^{-19}= 4.16 × 10^{-19} J ORA Energy of photon is less than work function so photoelectrons will not be emitted	M1 A1	**Allow** photon has 2.37 eV of energy **Allow** conclusion based **5 c i** **Examiner's Comments** To explain whether photoelectrons will be emitted, candidates needed to convert the work function measured in electron volt to joule. A clear conclusion was needed.
			Total	**11**	
3 8		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 increase as H moves towards the detector • if A is much greater than a then variation will be difficult to detect.	B1	allow absorbed or similar word for attenuated.
		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**	
3 9		i	Place a microphone close to loudspeaker and connect it to the oscilloscope.	B1	**Allow** 'connect oscilloscope to the signal generator (which is connected to the loudspeaker)'
		i	Measure the number of divisions between neighbouring peaks of the signal. (AW)	B1	
		i	The separation between the neighbouring peaks should be 3.6 divisions.	B1	
		ii	The sound is diffracted at each slit.	B1	
		ii	The diffracted waves interfere in the space beyond the slits.	B1	

		ii	There is loud sound / maxima / constructive interference when phase difference is zero or when path difference $n\lambda$.	B1	
		ii	There is quiet sound / minima / destructive interference when phase difference is 180° or when path difference is $(n + ½)\lambda$.	B1	
		iii	$x = 2 \times 0.75$ (= 1.5 m)	C1	
		iii	$\lambda = \frac{0.40 \times 1.5}{5.0}$	C1	
		iii	$\lambda = 0.12$ (m)	C1	
		iv	$v = 2800 \times 0.12$ $v = 340$ (m s^{-1})	B1	Possible ecf from **(iii)**
		v	Position does not depend on intensity, hence no change.	B1	
		v	Intensity decreases	M1	
		v	by a factor of 4.	A1	
			Total	**14**	