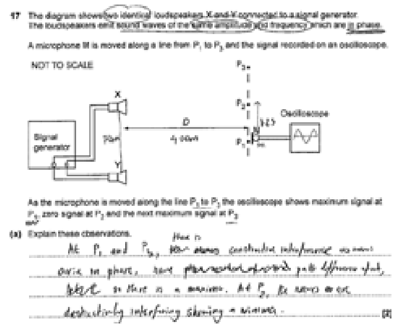
Mark scheme

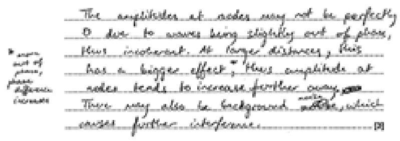
Question			Answer/Indicative content	Marks	Guidance
1			**B**	1	**Examiner's Comments** Candidates performed well on this question by correctly identifying that the Young's double-slit experiment does not demonstrate the property of refraction of light to give the correct answer B.
			Total	**1**	
2			**A**	1	**Examiner's Comments** Some candidates correctly calculated the wavelength of radiation to be 6.4x10^{-7}m by determining that the fringe width was 9 mm/6 = 1.5 mm. Therefore, the most common distractor was answer B as candidates had used the value of 9 mm as the fringe width and had therefore not understood that the fringe width is the distance between successive bright fringes. Giving the answer B did demonstrate an understanding of consistent units by correctly converting mm to m.
			Total	**1**	
3			**D**	1	**Examiner's Comments** Overall, candidates performed well on this question as they correctly identified that the path difference for constructive interference is λ to give answer D. The most common distractor was B as some candidates confused the path difference for constructive interference with destructive interference.
			Total	**1**	
4			**D**	1	**Examiner's Comments** Many candidates correctly determined the correct phase difference as p between points **X** and **Y** as they

					interpretated that the fraction of the wave between points **X** and **Y** was the equivalent to λ/2. The most common distractor was C.
			Total	**1**	
5	a		At P_1 (and / or P_3), waves (arrive) in phase <u>and</u> undergo constructive interference At P_2, waves (arrive) in antiphase <u>and</u> undergo destructive interference	B1 B1	**Allow** maxima / loud areas for at P_1 and P_3 **Allow** phase difference of 0 or 2nπ (rad) or 360° **Allow** explanation in terms of path difference (path difference = nλ and undergo constructive interference) **Allow** superposition for interference **Allow** minimum / quiet areas for P_2 **Not** just "out of phase" **Allow** completely out of phase / out of phase by (2n+1)π (rad) or 180° **Allow** explanation in terms of path difference (path difference = (n+1/2) λ and undergo destructive interference) **Allow** superposition for interference **Do not allow** deconstructive for destructive <u>**Examiner's Comments**</u> Candidates needed to appreciate that the maximum and minimum were due to interference and then give an explanation of constructive and destructive interference in terms of phase or path differences. It was a common misunderstanding that a stationary wave was formed, and a significant number of candidates described the observations in terms of nodes and antinodes. It was also common to see confusion between path and phase difference, with candidates giving phase differences in terms of wavelengths. Exemplar 1

					 In Exemplar 1, the candidate has given an excellent response to the maximum - stating constructive interference and then giving two reasons why this occurs (assuming n is an integer). However, the minima stops and isn't developed, even though there is still some space, and the additional space at the back can also be used. It is likely that the candidate knew the reason for the destructive interference, and this demonstrates how important it is to complete descriptions and explanations.
	b		$\lambda = (\frac{ax}{D} =) \frac{0.70 \times 2.5}{4}$ = 0.4375 (m) $f = \frac{v}{\lambda} = \frac{340}{0.4375} = 780$ (Hz)	C1 C1 A1	**Allow** λ = 0.44 (m), then *f* = 770 (Hz) Correct to at least 2sf **Special case:** use of *x* as 1.25 leading to *f* = 1554 (Hz) for 1 mark **<u>Examiner's Comments</u>** The majority of candidates were able to use the two source formula, however used 1.25m for their value of x, rather than double this. A small number of candidates attempted a geometrical solution, attempting to calculate angles, but this was unlikely on its own to score any marks.
	c		Amplitude / maximum (of the signal) larger than previous amplitude seen <u>at P_1</u> (and at P_3) Non-zero amplitude seen <u>at P2</u>	B1 B1	**Ignore** numerical value of how much the amplitude is larger **Allow** reference to P_3 alone **Allow** height or signal for amplitude throughout **Ignore** "louder" **<u>Examiner's Comments</u>** This question specifically asked about

					the observed signal and so responses based on loudness or sound volume are not appropriate. Candidates needed to be very clear that they were describing particular positions and how the signal varied from the previous situation. There was no penalty for an incorrect value of the increase in signal, although many candidates were able to state this correctly.
	d	i	power per unit area (perpendicular to the direction of energy transfer)	B1	**Allow** energy per unit time for power **Allow** equation in words, or in symbols with all symbols defined **Do not allow** power per area or power over area **Examiner's Comments** Candidates need to give a clear and specific answer to this question, which is best expressed in words. The Data and Formulae booklet contains the equation for intensity in symbols, however it is important to state the 'per unit area' in the explanation rather than a vaguer statement such as 'power over area'. Many candidates gave very simplistic responses such as 'the amount of energy a wave has' indicating a lack of appreciation for the detail required.
		ii	intensity is proportional to $(\text{amplitude})^2$ amplitude in (a) = 2 and amplitude in (c) = 3 (ratio of amplitudes = 3/2) so factor = 9/4 (or 2.25)	C1 C1 A1	**Allow** *A* (or *a*) for amplitude and *I* (or i) for intensity in both C marks **Allow** any valid ratio e.g. 9:4 **Examiner's Comments** Some candidates were able to correctly calculate the factor, which could be expressed in a number of ways. Many candidates were able to correctly state the relationship between intensity and amplitude but not able to identify how the amplitudes were different and so could not carry on with the calculation, so only scoring a single mark.
			Total	**11**	

6		i	Path difference = (20.2 – 12.2 =) 8.0 cm Path difference = $\left(\frac{8.0}{3.2} =\right) 2.5\ (\lambda)$ Destructive interference	C1 M1 A1	**Examiner's Comments** High scoring candidates showed their method clearly. It was expected that candidates would determine the path difference and then determine the path difference in terms of the number of wavelengths (2.5). There were some excellent explanations in terms of destructive interference occurring when there was an odd number (5) of half wavelengths.
		ii	Path difference = (19.7 – 12.5 =) 7.2 cm Path difference = $\left(\frac{7.2}{3.2} =\right) 2.25\ (\lambda)$ $\frac{\pi}{2}$ (rad)	C1 C1 A1	**ALLOW** 1.6 (rad) OR $\frac{9\pi}{2}$ OR 14 (rad) **Examiner's Comments** Candidates who scored well on this question showed their working clearly. Many clearly stated the path difference and determined that this path difference corresponded to 2.25 wavelengths. Some candidates struggled changing this to radians. **Assessment for learning** Candidates need to understand the radian and how to covert between degrees and proportion of a wavelength.
			Total	**6**	
7		i	Incident and reflected waves interfere / superpose AW Constructive interference /waves in phase gives maximum amplitude / anti-nodes Destructive interference/waves in antiphase gives minimum/zero amplitude / nodes	B1 B1 B1	**IGNORE** super impose **Examiner's Comments** About a third of candidates achieved no marks on this question but most candidates were able to correctly explain that a stationary wave is formed from the superposition of the incident and reflected wave. Often descriptions of nodes and antinodes was confused and lacked effective and correct use of scientific language by referring to constructive and destructive interference and explaining how these formed antinodes and nodes respectively.

		ii	intensity/amplitude/energy of wave decreases with distance / ORA AW reflected wave has a lower amplitude than incident wave ORA **OR** incomplete destructive interference occurs AW Difference in amplitudes increases with increasing distance from A ORA	B1 B1 B1	**ALLOW** energy absorbed when wave incident on the plate **<u>Examiner's Comments</u>** Candidates performed less well on this question with only about a third of candidates achieving 1 or more marks. Candidates had to explain both observations regarding the amplitudes of the nodes to fully access the question by interpreting that the change in amplitude was related to the decrease in intensity/amplitude of the reflected wave as it travelled a greater distance from the reflecting sheet **A**. Exemplar 1  The amplitudes at nodes may not be perfectly 0 due to waves being slightly out of phase, thus incoherent. At larger distances, this has a bigger effect, thus amplitude at nodes tends to increase further away. There may also be background [illegible], which causes further [illegible]. [3] This response is an example of a typical response where candidates have confused the change in amplitude of the nodes to either a change in frequency or phase difference due to the reflected wave being 'out of phase' with the incident wave. There was also a common misconception that the reflected wave from the reflecting sheet **A** had experienced interference from either background noise or from further reflections of the wave in the room. The candidates had assumed that the two waves were no longer coherent, and this resulted in a difference in the amplitude of the nodes further from the reflecting sheet **A**.
		iii	$\lambda = 2 \times 0.84 = 1.68$m 336 (m s^{-1})	M1 A1	**<u>Examiner's Comments</u>** Candidates performed well in this question as two thirds correctly determined that the wavelength of the sound wave was twice the distance

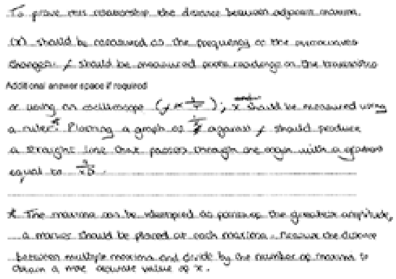
					between the adjacent nodes and then applied the wave speed equation *v* = *f*λ to calculate the speed of sound waves as 336 m s^{-1}.
		iv	**Any one from:** Measure across more than one minima Use lower frequencies Repeat and calculate means	B1	**ALLOW** use longer wavelengths **Examiner's Comments** Less than half of candidates were able to suggest a suitable improvement to the student's method to reduce uncertainty in their calculated value of the speed of sound waves in air as suggestions were often referenced to carrying out repeats but omitted that an average needed to be calculated from repeat readings to improve accuracy. Most candidates did not understand that simply increasing measurements across more nodes would have reduced the uncertainty or that by decreasing the frequency the wavelength increased and hence the uncertainty was reduced.
			Total	**9**	
8			(Provides evidence of) wave nature of electrons Light circles caused by constructive interference / waves arriving in phase Dark circles caused by destructive interference / waves arriving in antiphase	B1 B1 B1	**ALLOW** out of phase by 180 / π **NOT** just out of phase **Examiner's Comments** Most candidates appreciated that this was evidence of the wave nature of electrons, although a simple statement of 'wave-particle duality' does not really explain what the evidence provides. Although the circles could be described in terms of probability of electrons arriving, in the context of the question the concept of interference of the electron-waves was sufficient and was clearly the explanation that many candidates had been given and close to one half of candidates were able to achieve full marks.
			Total	**3**	
9	a		Waves arrive in phase / path difference of whole number of wavelengths	C1 A1	Phase difference = 0 or path difference = nλ **Examiner's Comments**

			Phase difference = 4π or 720^0/ with a path difference of 2λ		Around half of the candidates were able to achieve at least 1 mark and had a good idea that the waves must arrive in phase. Some candidates confused path difference and phase, giving statements such as 'the phase difference is one wavelength'. Only a small number of candidates appreciated that this was a maximum two away from the central maximum and so had a path difference of 2 × wavelengths (or equivalent in phase). Many candidates who did not score gave responses in terms of superposition but gave little detail beyond the use of the terms.
	b		$\lambda = a\,x / D = 640\times10^{-9} = 1.00\times10^{-5} \times x / 4$ (= 0.256 (m)) B to C = 2*x* = 0.512 (m) $\theta = \tan^{-1}(0.512 / 4) =$ **7.3** (°) Alternative method: Use of $n\lambda = d \sin\theta$ substitution of λ and *d* with any integer value of n recognition that n = 2 $\theta = \sin^{-1}(2 \times 640 \times 10^{-9} / 1.00\times10^{-5}) =$ **7.4** (°)	C1 C1 A1 (C1) (C1) (A1)	Correct substitution 0.256m assumes correct substitution Recognition that B-C is two fringe separation, and evaluation Correct to at least 2 significant figures **ALLOW** $\theta = \sin^{-1}(0.512 / 4) = 7.4$ (°) Note: RAD mode in calculators (0.127) MAX 2 marks Note: No doubling of *x* with correct working leading 3.7° MAX 2 marks e.g. $n\,x = 1.00\times10^{-5} \times \sin\theta$ where n is an integer Correct to at least 2 significant figures Note: only allow use of incorrect value of *n* = 1, leading to 3.7° MAX 2 marks Note: RAD mode in calculators (0.128) MAX 2 marks **<u>Examiner's Comments</u>** There was a roughly equal spread between 0, 1, 2 and 3 marks on this question and it illustrated the variety of ways in which the candidates attempted it. This calculation could be

					attempted in a number of ways; each of which would produce the correct final value. Most candidates who made an attempt were able to determine the fringe separation distance on the screen, generally by using the double slit formula. Only around a quarter of candidates appreciated that maximum **B** was the two away from the central maximum which was needed for the correct answer. Use of the diffraction grating formula gave a similar mark distribution. It is to be noted that, **in general,** incorrect answers with no working will gain no marks and it is very important that candidates who show no working run the risk of not gaining marks. In this case, an incorrect response of 3.7° could gain 2 marks as it was very evident where it came from.
	c		Interference given in A and D and/or B and C A and D diffraction **OR** A and D = destructive interference / destructive superposition **AND** B and C = constructive interference / constructive superposition	B1 B1	**IGNORE** superposition alone **Examiner's Comments** Most candidates were able to appreciate that the pattern in **Fig. 16.1** was an interference pattern and that the 'dark and light' were the result of interference. The first mark could also be credited for the use of the term 'diffraction' as at that point the single slit diffraction pattern is dominant.
	d		The waves have a constant/same/fixed phase relationship	B1	Constant/same/fixed phase difference **IGNORE** in phase, frequency, wavelength, diffraction and other correct physics **REJECT** incorrect references to amplitude and other wave properties **Examiner's Comments** Coherence is a term that candidates will likely have come across many times in their study of waves. While many candidates had an appreciation that it was related to phase, there were many responses that it was

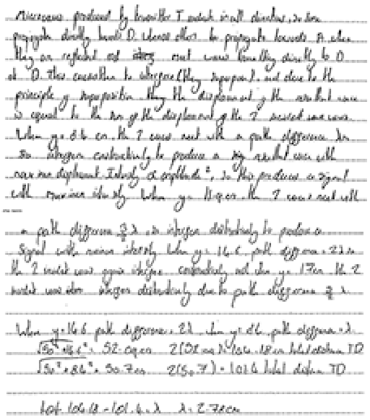
					when two waves were in phase. Around half of candidates were able to correctly explain coherence.
			Total	**8**	
10		i	***Level 3 (5–6 marks)** Clear explanation **and** clear description *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear explanation **or** clear description (but not both) **or** Some explanation **and** some description *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 description *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 × 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Explanation of pattern** • Interference / superposition occurs • Path difference a whole number of wavelengths • means waves are (exactly) in phase (or $\Delta\varphi = 0$) • giving (maximum) constructive interference • which leads to maximum intensity • Path difference an odd number of half wavelengths (or $\Delta\varphi = \pi$ radians) • means waves are in antiphase • giving (maximum) destructive interference • which leads to minimum intensity **Description of relationship between f and x** • $\lambda = ax/D$ **and** $c = f\lambda \rightarrow x = cD/af$ • so $x \propto 1/f$ (provided a and D remain constant) • Use ruler along QP to measure x (or $10x/10$, say) • Connect oscilloscope to transmitter or detector to measure f • Vary f (keeping a and D constant) and measure corresponding x • Calculate fx which should remain constant • Or plot graph of $1/x$ against f (or x against $1/f$)

					• Should give straight line <u>through the origin</u> **<u>Examiner's Comments</u>** There were three parts to this LoR question and all needed to be addressed to access the top level. Candidates were first asked to explain why a pattern of maximum and minimum intensity was observed. Marks were given to candidates who used precise scientific wording, e.g. destructive interference occurs when waves are in antiphase (rather than merely out of phase) or when the path difference is an odd number of half wavelengths (rather than merely an odd number of wavelengths). Fewer marks were given to candidates who wrote about waves 'cancelling out' or 'amplitudes subtracting'. In the second part, the expected relationship between the frequency f and the distance x is that f and x are inversely proportional. Most candidates were able to explain this, either algebraically ($\lambda = ax/D$ and $c = f\lambda$ so $x = cD/af$) or descriptively in terms of the waves overlapping more closely as f increased. The third part of the question required an explanation of how to verify this inversely proportional relationship. The question stated that the frequency f of the microwaves could be adjusted. So the experimental procedure involved varying f and measuring x (over several maxima for accuracy). If a graph of f against $1/x$ gives a straight line through the origin then the relationship is verified. Exemplar 3

					 The exemplar above shows a successful response for the third part of the question. It makes it clear what to vary, what to measure, what measuring instruments to use, and what to do graphically with the results. **Assessment for learning** Only use the words node and antinode in the context of stationary waves.
		ii	At 90° rotation, (interference) pattern disappears At 180° rotation, intensities are the same as at 0° but the maximum/minimum positions are switched / reversed Waves with polarisations at 90° to each other do not interfere / only waves with same polarisation interfere / only waves with a component in the same plane interfere	B1 B1 B1	**Allow** constant intensity along PQ **Not** zero intensity along PQ **Allow** <u>from 0 to 90°</u> the intensities of the maxima decrease (and the minimum intensities increase) **Allow** <u>from 90 ° to 180 °</u> the intensities of the maxima increase (and the minimum intensities decrease) but the maximum/minimum positions are switched / reversed from between 0 and 90° **Allow** waves must <u>oscillate</u> in same plane to interfere **Ignore** at 90° rotation, only waves from Y are detected at D because D can only detect vertical polarised waves <u>**Examiner's Comments**</u> This question was misread by many candidates, who described the variation in *overall* intensity instead of the variation in the *interference pattern*. Some candidates thought that transmitter **X** was rotating away from **Y**, rather than about the **AB** axis.

					Only a few candidates correctly explained the change in pattern in terms of the change in the amount of interference between the waves from **X** and **Y**. Many said detector **D** was receiving less of a signal from **X**, rather than interference was lessening because of a reduction in the vertical component from **X**.
			Total	**9**	
11			540 (°) 1.5 (λ)	B1 B1	**Allow** 180° **Do not allow** answer in radians **Allow** 3/2 **<u>Examiner's Comments</u>** This was a well done question overall; most candidates were able to appreciate that destructive interference resulted from a half number of cycles. Generally, the phase difference seemed to be better understood than the path difference, where incorrect responses for the path difference included a common response of $(n+1/2)\lambda$, or sometimes 0.5, showing an understanding of destructive interference but not applying it correctly to this situation.
			Total	**2**	
12			B	1	**<u>Examiner's Comments</u>** Most candidates identified the answer as B by correctly applying $\lambda = a\,x / D$ and the relationship between λ, a and x when D is constant.
			Total	**1**	
13			C	1	**<u>Examiner's Comments</u>** Candidates did not perform as well on this question with just a small majority of candidates determining the correct answer C. For A, B and D the path difference between a and b corresponds to either a whole or a half number of wavelengths so the waves must either be in phase or anti-phase.

			Total	**1**	
14			**Level 3 (5–6 marks)** Clear explanation of the maxima and minima **and** uses the results to determine the path difference leading to a value for wavelength. *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 maxima and minima **and** some attempt to use the results to determine the path difference leading to a value for wavelength. OR some explanation of maxima and minima **and** uses the results to determine the path difference leading to a value for wavelength. *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 of maxima and minima OR some attempt to use the results to determine the path difference leading to a value for wavelength. *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 mark** No response or no response worthy of credit.	B1 × 6	***Indicative scientific points may include:*** **Explanation of maxima and minima** • Two (or more) waves meet at D • Superposition • Displacements added • Minima not zero since path is longer via the reflector • Coherence: constant phase difference due to same source • Changing *y* changes the path difference • Discussion of path difference for maximum and minimum • Discussion of phase difference of maxima and minima • When path difference changes by λ/2 then maxima changes to minima or minima changes to maxima ***Determination of path difference and wavelength*** • Use of Pythagoras to determine path length • Attempt to find a path difference • Path difference repeated • Path differences 1.4, 2.8, 4.2, 5.6 (cm) • Wavelength = 2.8 cm **<u>Examiner's Comments</u>** To answer this question well, candidates needed to explain why there were maxima and minima. Many correctly explained the different paths but some were confused between phase difference and path difference. A significant number of candidates incorrectly discussed standing waves or two source interference. Most successful candidates clearly used the data correctly using Pythagoras to work out path

					differences and they realised that the difference between the two maxima or the two minima was the wavelength, however other candidates often just stated 14.6 – 8.4 was the wavelength or 11.9 – 8.4 × 2 was the wavelength. Exemplar 2  This candidate scored full marks – the scientific content of the response meets the Level 3 descriptor, and the communication statement is also met so six marks. The candidate structures the response by initially describing the experimental arrangement. There is appropriate scientific detail explaining how waves arrive at D. Importantly the candidate states that the resultant displacement is equal to the sum of the displacements of the individual waves. Although the phase change has not been discussed, there is a sensible discussion of path difference using the data given. Towards the end of the response the candidate clearly demonstrates how the wavelength of the microwaves may be calculated using Pythagoras calculations of the path difference and relating the path difference to the wavelength.
			Total	**6**	