Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		$\lambda = \frac{v}{f}$ $(= \frac{340}{262})$ $\lambda = 2L$ $(L =)\ \frac{1.30}{2} = 0.65$ (m)	B1 B1 B1	Formula may be implied by substitution **Allow** *c* for *v* Relationship may be inferred from a correct diagram of fundamental drawn in a tube open at both ends,or from a statement such as 'half a wavelength fits inside the tube' Some working leading to correct answer must be shown; don't accept a bald answer **Allow** L = 0.649 (0.64885) as evidence of working Do not allow working backwards from the answer **<u>Examiner's Comments</u>** This is a 'show that' question and so every step of the calculation needs to be made clear. It is not enough to point out that 340 / (2 × 262) = 0.65: the examiner needs to know why the data is being combined in this particular way. The step that was most often omitted was saying that, for the fundamental (lowest) frequency, half a wavelength fits inside the flute. This could be demonstrated using a diagram, showing an open tube containing half a wavelength with antinodes at both ends. However, a written statement (length is half of a wavelength) or a mathematical statement ($L = \lambda/2$) are just as good.
	b	i	Any **two** from • particles occupy negligible volume (compared to volume of container/gas) • collisions are (perfectly) elastic • time of collisions is negligible (compared to the time between collisions) • negligible <u>forces</u> exist between particles (except during collisions)	B1 × 2	Mark as for Short Answer Questions (requiring only a list by way of a response) and contradictory responses see page 3. **Allow** zero / no / none for negligible throughout **Ignore** particles occupy negligible space **Ignore** particles are very small **Allow** <u>kinetic</u> energy is conserved (during collisions) **Allow** the particles move at constant velocity (in between collisions) **Ignore** type of force if specified **<u>Examiner's Comments</u>** Most candidates confidently wrote two correct assumptions. Errors most often came about through careless wording, such as 'the time between collisions is

					negligible' (rather than the time of collisions) or 'the particles take up negligible space' (rather than volume).
		ii	$M = 4.00 \times 10^{-3}$ (kg mol^{-1}) $T = 263$ (K) $v^2 = \frac{1.67 \times 8.31 \times 263}{4.00 \times 10^{-3}}$ $v = 955$ (m s^{-1}) $f = (\frac{v}{\lambda} =) \frac{955}{1.30} = 730$ (Hz) **Alternative method using ratios** $\frac{f_1}{f_2} = \left(\frac{\gamma_1 T_1 M_2}{\gamma_2 T_2 M_1}\right)^{1/2}$ or $\frac{v_1}{v_2} = \left(\frac{\gamma_1 T_1 M_2}{\gamma_2 T_2 M_1}\right)^{1/2}$ $T = 263$ (K) $\left(\frac{\gamma_1 T_1 M_2}{\gamma_2 T_2 M_1}\right)^{1/2} = \left(\frac{1.67 \times 263 \times 29}{1.4 \times 293 \times 4}\right)^{1/2}$ $= 2.786$ f (= 2.786 × 262) = 730 (Hz)	C1 C1 C1 A1 C1 C1 C1 A1	This C1 mark is for converting *M* into kg mol^{-1} **Allow ECF** for an incorrect POT in *M* *T* = -10 (K) is **XP** onwards (first C1 mark can still be scored) but **allow ECF** for incorrect conversion of *T*. This C1 mark is for correct substitution into the given formula; v^2 does not need to be calculated for the mark but seeing *v* = 955 implies the mark **Allow** *M* given to 1sf **Allow** 8.3 or *R* for 8.31 If a value for γ or *M* is taken from the wrong row of the table, this is a TE (*M* must be in kg/mol). If both wrong values are used, count this as a single TE. **ECF** candidate's value of λ or (λ = 2L) from 1a **Allow** *f* = 740 (Hz) For reference, POT error in *M* gives *v* = 30.2 (ms^{-1}) and *f* = 23 (Hz) *T* = −10 (K) is **XP** onwards (first C1 mark can still be scored) but **allow ECF** for incorrect conversion of *T* This C1 mark is for substitution and the ratio 2.786 does not need to be calculated for the mark The values for *M* may be given in kg/mol or left in g/mol as long as there is consistency **Allow** *M* = 4 to 1sf **Allow** *f* = 740 (Hz) If using $\frac{v_1}{v_2}$ then v = 2.786 × 340 = 947 giving *f* (= *v* /λ = 947 / 1.3) = 730 (Hz) but **ECF** candidate's own value of *λ* or *L* (*λ* = 2L) from 1a **<u>Examiner's Comments</u>** **Common problems in 1 (b) (ii)** • failing to convert the molar mass *M* into units of kg mol^{-1} • substituting the length of the flute (0.65m) instead of 1.30m for the wavelength.
			Total	**9**	

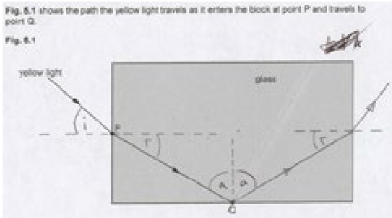
2	a		Calculates gradient using at least half the graph *eV=hf* **Or** *h=gradient* × 1.6 × 10^{-19} *h = 3.5* × 10^{-34} J s	B1 C1 A1	Minimum range of x value 3.5x10^{14} Range 3.4 to 3.5 × 10^{-34} J s 2sf **<u>Examiner's Comments</u>** There was some variability in performance with this question, but many responses achieved 3 marks for a correct calculation and value for the Planck constant using data from the graph. The most common reason for responses being given 0 marks were for an error in their gradient calculations for either taking readings from less than half the graph, or for not including the correct power for frequency 10^{14}. Some candidates did correctly calculate the gradient from the graph, but then did not select and apply eV=hf to calculate a value of the Planck constant.
	b		$\frac{6.63 \times 10^{-34} - 3.5 \times 10^{-34}}{6.63 \times 10^{-34}}$ 47%	C1 A1	**ECF** from (b) **Allow** range 47% to 49% **Not** 50% from 52.8% if calculated from 3.5×10^{-34}/6.63×10^{-34} **<u>Examiner's Comments</u>** Candidates did not perform well on this question as many candidates were given 0 marks. The most common reason for candidates not achieving marks was for not calculating a difference between the calculated and accepted value for the Planck constant with many candidates carrying out the calculation calculated value/accepted value x 100%. **Assessment for learning** Please refer to page 36 of the Practical Skills Handbook for information on correct methodology on calculating percentage difference between calculated and accepted values.
			Total	**5**	
3			**B**	1	**<u>Examiner's Comments</u>** This question was answered well as candidates were able to apply knowledge and understanding of electromagnetic waves passing through a polarising filter to give the correct answer B.
			Total	**1**	

4			**A**	1	**Examiner's Comments** Candidates performed well on this question as they determined that when a wave passes through a gap with a similar size to its wavelength, it results in greater diffraction to give the response A.
			Total	**1**	
5	a		$\lambda = (\frac{ax}{D} =)\ \frac{0.70 \times 2.5}{4}$ = 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 **Examiner's Comments** 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.
	b		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" **Examiner's Comments** 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.
	c	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 (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	**9**	
6			B	1	**Examiner’s Comments** Most candidates were able to correctly calculate the amplitude and frequency. **A** was the most common distractor where candidates simply identified the time period rather than then calculate the frequency.
			Total	**1**	
7	a	i	510 (THz)	B1	**Allow** correct answer in answer space **Examiner’s Comments** Most candidates were able to calculate the frequency, however, many candidates did not allow for the table heading in THz. **Assessment for learning** Candidates should be able to record data in a table using the units given in the column headings.
		ii	**Glass** 1.97×10^8 387 510	B1 B1	**Allow ECF** for wavelength for correct speed of wave / same frequency as **(a)(i)** **Allow** 386, for 387 **Allow** 2sf answers, e.g. 2.0×10^8 390

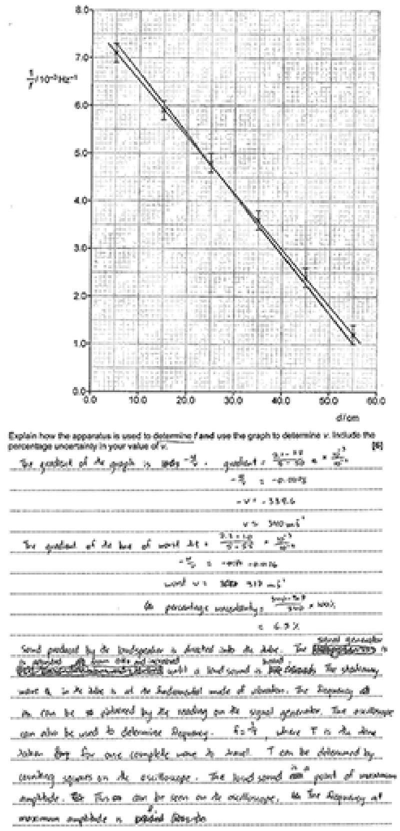
			One correct scores one mark All correct and in the table scores two marks		510 **ECF** from **(a)(i)** **Ignore** units in table **<u>Examiner's Comments</u>** Most candidates were able to calculate the speed of light in glass correctly. Lower scoring candidates often incorrectly believed that the frequency (as opposed to the wavelength) decreased in glass. **Misconception** Many candidates did not fully understand effects of refraction on the quantities speed, frequency, and wavelength.
	b	i	Normal drawn 90° to the surface at P (by eye) **and** angle between normal and incident ray labelled *i* **and** angle between normal and refracted ray labelled *r*	B1	**<u>Examiner's Comments</u>** This was generally answered well with many candidates adding a labelled normal line. Some lower scoring candidates did not draw a normal and just marked the angles between the rays and the boundary of the two mediums.
		ii	Any **four** from: • Use a single slit / yellow filter (in the ray box) • Use of dim lighting / darkened room • Draw around the glass block • Use a protractor to measure 90° for the normal OR to measure angles • Draw crosses / use pins (a long way apart) on the <u>incident</u> ray / mark incident ray (with ruler) • Mark point Q • (Remove block and) then join P to <u>marked</u> point Q	4 x B1	**<u>Examiner's Comments</u>** This question was designed to give candidates the opportunity of describing a practical technique. In this question, the basic set-up required a single slit and a yellow filter in the ray-box to produce the thin ray of yellow light. It is often easier to carry out this experiment in a darkened room. Few candidates gave details of how the rays would be traced and the need to draw the outline of the glass block. High scoring candidates often included detail about placing small crosses on the rays and then using a rule joining them together and removing the block to join points P and Q. Some candidates also discussed the drawing of the normal and using a protractor to measure the angles. **Assessment for learning**

					Students should have the opportunity of developing their practical skills so that they are able to describe methods and suggest improvements to obtain accurate data.
		iii	$\sin r = \frac{\sin 49.9}{1.52}$ OR $r = \sin^{-1}\left(\frac{\sin 49.9}{1.52}\right)$ OR $\sin r = 0.503$ OR $r = \sin^{-1}(0.503)$	M1 A0	**Examiner's Comments** To gain credit, candidates needed to show the correct substitution of the data into the correct equation and evaluate the answer.
		iv	Angle of incidence, i = (90-30 =) 60° $C = \sin^{-1}\left(\frac{1}{1.52}\right) = 41(°)$ $i > C$	M1 M1 A1	**Allow** 59.8° (use of 30.2°) **Allow** ECF from (b)(iii) **Allow** 60(°)> 41(°) Do not allow 49.9 > 41 **Examiner's Comments** Candidates needed to determine the both the critical angle and the angle of incidence at point Q. Many candidates were able to calculate the critical angle. Since this was a show question it was then expected that there would be an appropriate conclusion that since the angle of incidence (60a) was larger than the angle of incidence, total internal reflection would occur. Some candidates showed mathematically that a refracted ray was not possible but did not link this with the criteria for total internal reflection. **Assessment for learning** Candidates should be able to state the conditions for total internal reflection and be able to apply these conditions to practical situations.
		v	Mirror image about vertical plane at Q by eye to where ray leaves the block and bends away from the normal	B1	**Ignore** other lines (since could be due to answering (ii) **Examiner's Comments** The majority of candidates did not realise that there should be a mirror image of the diagram. High scoring candidates answered this question well by adding appropriate lines to the diagram and adding where the angles were equal. **Exemplar 2**

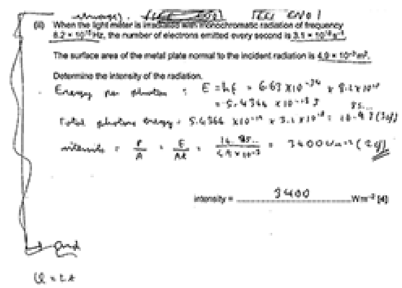
					 The candidate has clearly shown the answer with the normal lines aligned and labelled the angles so that it is clear which ones are equal. This candidate has also clearly shown the angle of incidence and the angle of refraction for Question 5 (b) (i).
			Total	**13**	
8	a		4 (ms) OR 0.004 (s) 250 (Hz)	C1 A1	**Allow** one mark for 0.25 (Hz) to any power of ten **Examiner's Comments** The majority of the candidates gained credit. Some lower scoring candidates did not interpret the trace correctly.
	b		One node drawn at closed end and one antinode drawn at open end N and A correctly labelled	B1 B1	**Examiner's Comments** Many candidates understood what was meant by an antinode and a node but did not understand that for the fundamental mode of vibration a node was formed at the closed end and one antinode was formed at the open end.
	c		(3×250=) 750 (Hz)	B1	**Allow ECF** from (a) **Not** ECF from (b) **Examiner's Comments** This question was challenging. A value of 500 Hz was the common incorrect answer. Other incorrect answers included candidates who thought that the frequencies decreased. **Misconception** Many candidates did not fully understand the formation of stationary waves in closed tubes and the effect on the harmonics. Candidates should have the opportunity of drawing stationary waves in both open and closed tubes and determining the wavelength and frequency for each pattern.

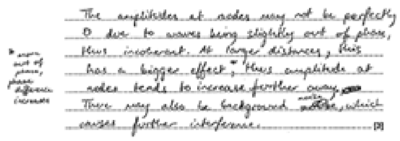
			Total	**5**	
9		i	number of large squares = 11± 1 no of squares × area of each = 11 x 1 x 10^{-25} = **1.1×10^{-24}** (J)	C1 A1	May be inferred from calculation Any valid method allowed (counting squares, trapezium rule, splitting area into regular shapes) **Allow** number of medium squares = 44 ± 4 **Allow** number of small squares = 1100 ± 100 **Allow** answers in the range 1.00×10^{-24} to 1.20×10^{-24} **Allow** answer to 1s.f. **Examiner's Comments** Candidates who counted squares underneath the curve almost always got areas with in the allowed range. Those who tried to use trapeziums or other regular shapes were usually less successful.
		ii	300 pc ≈ 300 × 3.1 × 10^{16} m (= 9.3 × 10^{18} m) ratio of areas = $\frac{4\pi(300 \times 3.1 \times 10^{16})^2}{3000} = \frac{1.09 \times 10^{39}}{3000}$ (= 3.6×10^{35}) energy = ratio of areas × area under curve = **4.0×10^{11}** (J)	C1 C1 A1	Mark is for working leading to the correct distance. Distance does not need to be seen explicitly but 9.3×10^{18} m implies C1 Mark is for working leading to the correct ratio. Ratio does not need to be calculated but 3.6×10^{35} implies C1 **Allow** calculation of inverse ratio (= 2.8×10^{-36}) **Ignore** unit if one is given Mark is for correct answer; **allow** answer to 1s.f. Answer = 3.6×10^{35} × candidate's answer to 3c(i) **Allow ECF** for incorrect calculation of area / energy in 3c(i) Expect an answer in the range 3.6×10^{11} to 4.4×10^{11} Note: candidates could also calculate the answer by using ratio of energies = ratio of powers or intensity of pulsar = intensity at telescope **Examiner's Comments** This question stretched even the highest ability candidates. The key was in realising that the intensity of the pulsar = the intensity at the telescope. So the ratio of powers (or energies) = ratio of surface areas. Most candidates successfully converted 300 pc into metres. However, some did not realise that the surface area of a sphere is $4\pi r^2$, a formula that is in the data, formulae and relationships booklet.
			Total	**5**	

10			**Level 3 (5–6 marks)** Clear description of method to determine *f* **and** graph analysed to determine *v* and the percentage uncertainty in *v* *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 description of method to determine *f* **and** some analysis of data to determine *v* or the percentage uncertainty in *v* **or** Limited description of method to determine *f* **and** graph analysed to determine *v* and an attempt to determine the percentage uncertainty in *v* **or** Clear description of method to determine *f* **and** limited analysis of graph *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 of the method to determine *f* **or** Limited analysis to determine *v* *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 mark** *No response or no response worthy of credit.*	B1 × 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description of method** • Adjust frequency until maximum amplitude observed / heard • Start from a low frequency • Since fundamental frequency is the lowest resonance • Measure period of wave on oscilloscope • Period = timebase x horizontal distance • $f = 1/T$ • read frequency from signal generator. **Analysis of data** • Gradient = $-\frac{4}{v}$ • Determines gradient of line (-0.012 Hz^{-1} m^{-1}) • Determines *v* (330 to 344 m s^{-1}) • Correct power of ten and unit • Draws worst acceptable line • Determines gradient of worst acceptable line • Calculates absolute uncertainty in gradient • Determines percentage uncertainty in gradient • Percentage uncertainty in gradient = percentage uncertainty in *v* **<u>Examiner's Comments</u>** The second level of response question gave candidates the opportunity of drawing conclusions from an experiment as well as explaining how the fundamental frequency *f* may be determined experimentally. For good answers to these type of questions, candidates need to structure their answers logically so that all parts of the question are answered. An explanation to determine *f* should include the adjustment of the frequency and how to determine the fundamental frequency with the idea of the loudest sound. More successful candidates discussed the peak on the oscilloscope and starting from a low frequency. It was also expected that candidates could describe how to determine the frequency from an oscilloscope. Ideally reference would be made to the time-base. To determine the value of *v* with the percentage uncertainty, candidates needed to show their working clearly, taking into account the powers of ten and units from the graph.

					Exemplar 3  This candidate’s response is structured and detailed. Firstly, this candidate has added the steepest worst acceptable line to the graph which passes through all the error bars. The candidate then identifies how the gradient is related to the frequency of the wave before calculating the gradient. The calculation of the gradient is demonstrated and the candidate has also clearly taken into account the powers of ten on each axis of the graph before determining *v* with a correct unit. This process is repeated for the worst acceptable line with each of the steps shown before percentage uncertainty is calculated. Throughout this section, it is easy to follow the candidate’s method. It is clear that the candidate has used a large triangle to calculate the gradient. The candidate then explains how *f* is determined by adjusting the signal generator until a loud sound is heard and then explaining how the frequency is determined by the oscilloscope.
			Total	**6**	

1 1	a	i	Transverse because the oscillations / vibrations are at right angles / perpendicular to the direction of travel / energy transfer	B1	**ALLOW** oscillations / vibrations vertical and direction of travel is horizontal **Examiner's Comments** Many candidates incorrectly stated that water waves were longitudinal waves. High scoring candidates referred to oscillations or vibrations of the water particles and the direction of travel of the wave or energy transfer.
		ii	Plane polarised because the oscillations / vibrations are all in the vertical / (only) one plane / direction	B1	**Examiner's Comments** Few candidates were able to explain why the waves were plane polarised. High scoring candidates stated that the oscillations were in the vertical plane only.
	b		2.5 (Hz)	B1	**Examiner's Comments** This question was very well answered.
			Total	**3**	
1 2		i	intensity of radiation is proportional to the rate of incident photons (above threshold frequency) AW (increased) one-to-one interaction between photons and electrons AW current is the rate of flow of charge/current = charge flow/time (so proportional to rate of electron release)	B1 B1 B1	**Examiner's Comments** Candidates did not perform well on this question as 60% of candidates achieved no marks. A common response was to describe that greater intensity leads to more photoelectrons which was not given, and few made the important connection between intensity and 'rate of photons hitting the plate'. Also, many candidates did not apply the 1:1 correlation between photons and electrons in the photoelectric effect as they simple stated that more electrons were released without applying knowledge of the individual interaction between incident photons to the release of electrons. Many took the reverse view that greater current led to greater intensity or simply referred to the ammeter reading rather than referencing current. Exemplar 2  Because the more intense the radiation is, the more electrons released from the metal. [illegible] As electrons have charge, this means when there are more electrons [illegible] in the circuit, the current will increase, so the ammeter reading will increase. This exemplar demonstrates a typical response from candidates where a simple statement is made in relation to the intensity of electrons emitted and corresponding current reading on the ammeter. As in many similar

					responses the intensity of radiation is not linked to the 'rate of incident photons' resulting in a similar 'rate of electron emission' due to the 1:1 interaction between photons and electrons. Candidates were then required to link the rate of electron emission to the equation $\Delta Q = I\Delta t$ to conclude that current is equal to the rate of flow of charge and hence the ammeter reading is proportional to the intensity of the radiation.
		ii	$6.634 \times 10^{-34} \times 8.2 \times 10^{15}$ / 5.44×10^{-18} J $5.44 \times 10^{-18} \times 3.1 \times 10^{18}$ / 16.9 (W) $\text{intensity} = \frac{16.9}{4.9 \times 10^{-3}}$ 3.4×10^{3} W m^{-2}	C1 C1 C1 A1	**ALLOW** 3439(.48)W m^{-2} **<u>Examiner's Comments</u>** Candidates did not perform well on this question as just over half of candidates scored 0 marks. Candidates had to select the equations $hf = \Delta E$ and $I = P/A$ from the Data, Formulae and Relationship booklet and then apply that the power was equal to the energy as the rate of emission of electrons was in a time of 1 second. Many candidates would select the correct equation $I = P/A$ but would then try and calculate power by using the equation $P = VI$ and $\Delta Q = I\Delta t$ by using the charge of an electron to calculate the current and using the battery e.m.f. of 3 V given in the circuit diagram. This demonstrated for a majority of candidates a lack of a confident understanding of the photoelectric effect that the energy of incident photons results in the release of electrons. Exemplar 3  This response demonstrates the correct and clear selection and application of formulae to calculate the intensity of the incident radiation.
			Total	**7**	
1 3	a		Molecules vibrate/oscillate oscillations parallel to the <u>direction</u> of the energy transfer / propagation Creating areas of high **and** low pressure	B1 B1 B1	**ALLOW** particles throughout **ALLOW** move back and forth **ALLOW** parallel to the direction of the wave **ALLOW** areas are high concentration/density **and** low concentration/density of molecules **NOT** ref. to varying amplitude

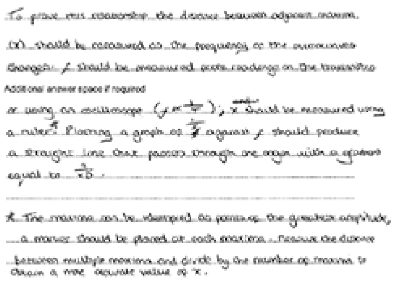
			Or regions where the molecules are closer together **and** further apart		**Examiner's Comments** Candidates' performance on this question was variable with about of half of candidates scoring 1 or 2 marks but few candidates achieving all 3 marks for correctly explaining the movement of air molecules in compression and rarefaction of longitudinal waves. Descriptions of the movement of particles to transfer energy as a longitudinal wave was often weak with limited use of scientific language such as oscillation and parallel. The most common mark that was given was for an explanation of how compressions and rarefactions are formed in reference to the proximity of air molecules.
	b	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 **Examiner's Comments** 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 noise, which causes further interference. [3] * more out of phase, phase difference increases 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	λ= 2 × 0.84 = 1.68m 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 $v = f\lambda$ 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 **<u>Examiner's Comments</u>** 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	**12**	
14			B	1	**<u>Examiner's Comments</u>** Only half of candidates correctly applied the behaviour of waves and understood that frequency of the waves remains constant when they travel through different media (different depths of water) and the wave speed equation to determine the correct answer B. Hence, the most common distractor was A. **Misconception** This is a common misconception that the frequency changes when waves travel through different media, whether it is water waves travelling through different depths of water or light when it travels through media with different refractive indices. When applying the wave speed

					equation $v = f\lambda$ the frequency remains constant, so v is directly proportional to λ.
			Total	**1**	
15			D	1	**Examiner's Comments** About half of candidates performed well on this question by determining the correct answer of D by understanding the behaviour and intensity of unpolarised light when transmitted through a polarising filter.
			Total	**1**	
16	a		${}^{18}_{9}F \rightarrow {}^{18}_{8}O + {}^{0}_{1}\beta^{+}$ $(+\nu)$	C1 A1	Correct fluorine isotope Correct equation **ALLOW** numbers written to right of symbol **ALLOW** e / e^{+} / $\bar{e}$ / β for positron symbol with correct numbers **IGNORE** gamma in products **ALLOW** ${}^{0}_{0}\nu$ for neutrino **ALLOW** v_e for neutrino **Examiner's Comments** Most candidates will have gained the first mark for the correct isotope of fluorine. Those who didn't likely reversed the positions of the nucleon and proton number. It was noticeable that a large number of candidates were unable to balance the equation and while they had the correct values for the positron, the oxygen isotope was incorrect.
	b		$E = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2$ $= 8.2 \times 10^{-14}$ (J) $E = hc / \lambda = 8.2 \times 10^{-14} = 6.63 \times 10^{-34} \times 3 \times 10^8 / \lambda$ $\lambda = 3.00 \times 10^8 \div 1.2367 \times 10^{20}$ $=$ **2.4×10^{-12}** (m)	C1 C1 A1	Working leading to evaluation of E **ALLOW** factor of 2 leading to 1.6×10^{-13} (J) **NOT** use of $\lambda = h/mv$ where v is 3×10^8 alone **XP** **ALLOW** use of $\lambda = hc/mc^2$ or $\lambda = h/mc$ **ALLOW** Use of electron mass = 0.511 MeV giving 8.2×10^{-14} (J) Correct to at least 2 significant figures Answer of 4.9×10^{-12} or 1.2×10^{-12} allow 2/3 due to incorrect accounting for factor of 2 **Examiner's Comments** Well over half of the candidates were able to score 2 or more marks on this question. A great deal scored 2 marks due to the inclusion of a factor of two, which was then not removed (or vice versa). Some candidates used the formula for kinetic energy – which by coincidence may give the correct answer – however this was not credited,

					nor was the more common use of the de Broglie formula. Examiners sometimes had a difficult decision on this question, whether the response was a physics error or not, and if in doubt a candidate would be awarded the marks.
	c		X-rays formed when <u>electrons</u> (in an atom) de-excite Gamma rays come from the decay of <u>nuclei</u> (in unstable isotopes)	B1 B1	**ALLOW** X-rays may be produced by acceleration / deceleration of (fast moving) electrons / X-rays are produced when (fast moving) electrons are incident on a metal target / X-rays may be produced when electrons lose kinetic energy **ALLOW** gamma rays come from (the decay of) radioactive <u>nuclei</u> / gamma rays come from the <u>nucleus</u> of unstable atoms / gamma rays come from the de-excitation of <u>nuclei</u> / gamma rays come from <u>annihilation</u> of particle-antiparticle (pairs) / **IGNORE** gamma from fission **<u>Examiner's Comments</u>** The main principle behind this question was to distinguish between the X-ray production by electrons and gamma ray production by nuclei. Fairly specific details were required for each, although a wide range of answers were accepted. This question discriminated well among the candidates with roughly equal fractions getting 0, 1 and 2 marks.
	d		The half-life is short Advantage: Exposure of the patient to <u>ionising</u> radiation is kept as low as possible. Disadvantage: (Radiographers have a) short time to scan/diagnose the patient	B1 B1 B1	**ALLOW** activity is high **IGNORE** it decays quickly **ALLOW** F18 has to be manufactured on site before use / high activity means exposure is high during handling **IGNORE** short time to treat the patient **<u>Examiner's Comments</u>** Although apparently a simple set of ideas, the detail required for this question meant that only a small fraction of candidates were able to gain full marks. It was necessary to state that the half-life was (relatively) short, which many of the stronger candidates did not do. The advantage to the patient requires the use of the term 'ionising' as this is the fundamental issue with the radiation. Similarly, candidates had to make it clear that the disadvantage was due to the short time to carry out the scan rather than just a statement of needing to work quickly.
			Total	**10**	
17			Interference given in A and D and/or B and C	B1 B1	**IGNORE** superposition alone

			A and D diffraction **OR** A and D = destructive interference / destructive superposition **AND** B and C = constructive interference / constructive superposition		**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.
			Total	**2**	
1 8		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> **Examiner's Comments** 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	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°

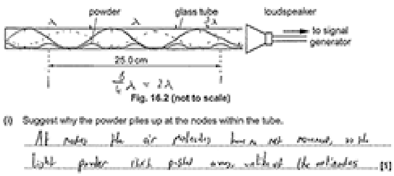
			interfere / only waves with same polarisation interfere / only waves with a component in the same plane interfere		**Allow** waves must oscillate in same plane to interfere **Ignore** at 90° rotation, only waves from Y are detected at D because D can only detect vertical polarised waves **Examiner's Comments** 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**	
19		i	$f = 1/T$ working shown to give $T^2 =$ $T^2 = \left(\frac{8\pi^2}{3g}\right)L$	B1 B1	**Allow** $T =$ $T = 2\pi\left(\frac{2L}{3g}\right)^{\frac{1}{2}}$ **or** $f^2 = 1/T^2$ Subject must be T^2 **Allow** $T^2/L = 8\pi^2/3g$ **Examiner's Comments** The expected response here was to start from the given relationship $f = \frac{1}{2\pi}\sqrt{\frac{3g}{2L}}$ and then use $T = 1/f$ to manipulate the expression into the form $y = mx + c$. Candidates who recognised this generally had sufficient skill in algebra to arrive at the correct answer.
		ii	$g = \left(\frac{8\pi^2}{3 \times 2.64}\right)$ $g = 9.97$ (ms^{-2})	C1 A1	Answer must be given to at least 3sf **Examiner's Comments** Candidates needed to substitute gradient = 2.64 into the formula $g = \frac{8\pi^2}{3 \times \text{gradient}}$ This was arguably the easiest question on the paper. Although almost all candidates scored both marks, a few lost a mark through thinking that 9.97 = 10.0 to 3sf.
		iii	line of worst fit drawn	B1	Steepest or shallowest possible line that passes through all the error bars (allow ±½ small square tolerance vertically) If two lines are drawn then they must both be correct **Examiner's Comments**

					A line joining the top of the furthest right hand error bar to the bottom of the furthest left hand error bar (or vice versa) passed through all the error bars. Either was accepted. A tolerance of ±½ small square was allowed at either end. The most common misconception was that the worst fit line joined the top of the right hand error bar to the top of the left hand error bar (or vice versa).
		iv	gradient of worst line calculated with large triangle working to find percentage uncertainty in *g* answer consistent with candidate's worst line	B1 M1 A1	$\Delta L \geq 0.06$m Shallowest gradient ≈ 2.1(s^2 m^{-1}) and steepest ≈ 2.9 (s^2 m^{-1}) $\frac{\text{worst value of g} - 9.97}{9.97}$ (x 100%) **Allow** % uncertainty in gradient = $\frac{\text{gradient of wfl} - 2.64}{2.64}$ (x 100%) Expect answer ≈ 10% (steepest wfl) and ≈ 27% (shallowest wfl) **Allow** a negative answer **<u>Examiner's Comments</u>** It is important to show all working in this type of question. Firstly, in checking the gradient of the worst fit line, the examiner needs to determine whether a large triangle has been used in the calculation. Therefore it is helpful if candidates draw the triangle they intend to use and write down all their read-offs. Secondly, the working to find the percentage uncertainty in *g* has to be shown in full because the correct answer is $\frac{\text{worst value of } g - 9.97}{9.97}$ and not $\frac{\text{worst value of } g - 9.97}{\text{worst value of } g}$ Although the percentage uncertainty in the gradient was not exactly the same as the percentage uncertainty in *g*, both methods were accepted.
		v	percentage difference = $\frac{9.97 - 9.81}{9.81}$ × 100% = 1.6% **or** absolute difference = 9.97 − 9.81 = 0.16 **or** absolute uncertainty = (9.97 − value of *g* from wfl) conclusion consistent with candidate's answer to **(b)(iv)**	M1 A1	Possible **ECF** from **(b)(ii)** Value for *g* is accurate if % uncertainty >% difference **or** if absolute uncertainty > absolute difference **or** if 9.81 lies within the uncertainty range for *g* **<u>Examiner's Comments</u>** Most candidates were able to calculate either the absolute or the percentage difference between the experimental result (9.97) and the true value of *g* (9.81). Many candidates wrongly called this the percentage uncertainty or the percentage error in the result, but their calculation

					was accepted anyway. A common misconception was that the relatively small percentage difference (1.6%) between the experimental result and the true values meant that the experiment was accurate. However, this is not necessarily the case. A result is only accurate if it is close to the true value and, unless we know the *uncertainty* in our result, we cannot judge whether or not this is the case. For example, suppose that the uncertainty in our result was 1% i.e. we found that g = 9.97±0.10. Then our result for g would *not* be accurate. Our result must be somewhere between 10.07 and 9.87, and the true value of g (9.81) lies outside this range.
			Total	**10**	
20		i	$\lambda_{max} \propto 1/T$ (T has decreased over time so in the past) the <u>peak</u> was at a shorter wavelength / further to the left on the graph	B1 B1	**Not** $\lambda_{max} = 1/T$ May be inferred from candidate's diagram **Ignore** overall shape of spectrum **<u>Examiner's Comments</u>** The mention of Wien's displacement law gave a clue that it would be useful in answering the question. A mark was given for stating the law. Note that the law is $\lambda_{MAX} \propto 1/T$ rather than $\lambda \propto 1/T$ or $\lambda_{MAX} = 1/T$. Candidates who did not draw on the diagram to illustrate their response sometimes missed the second B1 mark because they said that the wavelength (rather than the <u>peak</u> wavelength) would have been smaller. If an examiner says, 'You may draw on the diagram', it is generally a beneficial approach.
		ii	$E\left(=\frac{hc}{\lambda}\right) = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.1 \times 10^{-3}}$ $E = 1.8 \times 10^{-22}$(J)	C1 A1	Full substitution needed if judging explicitly **<u>Examiner's Comments</u>** This was a straightforward question and most candidates correctly chose and applied the formula $E = \frac{hc}{\lambda}$ **Common problems in 4(b)(ii)** • not converting mm to m • trying to convert the answer to or from MeV
		iii	**EITHER** $\frac{3 \times 10^{-6}}{1.8 \times 10^{-22}}$ **or** 1.66×10^{16} (photons m^{-2} s^{-1}) **OR**	C1	**Allow** 2×10^{14} (s^{-1}) or 3×10^{14} (s^{-1}) Expect to see $1.66 \times 10^{16} \times 150 \times 10^{-4}$ **or** $\frac{4.5 \times 10^{-8}}{1.8 \times 10^{-22}}$ **<u>Examiner's Comments</u>**

			$3 \times 10^{-6} \times (150 \times 10^{-4})$ **or** 4.5×10^{-8} (W) number of photons per second $\left(= \frac{3 \times 10^{-6} \times 150 \times 10^{-4}}{1.8 \times 10^{-22}}\right)$ $= 2.5 \times 10^{14}$ (s^{-1})	A1	This is a complex, multi-stage calculation. A good approach was to use: number of photons per second × energy of each photon = amount of energy per second = power = intensity × area The total intensity of the microwave background radiation was given at the start of the question as 3×10^{-6} Wm^{-2}. Converting cm^2 into m^2 proved difficult for many.
		iv	$E = Pt = IAt$ and $V = Ah$ where A is CSA of cylindrical tank and h is height of tank $\Delta\theta = \frac{E}{mc} = \frac{IAt}{\rho A h c} = \frac{It}{\rho hc}$ and so $\frac{\Delta\theta}{t} = \frac{I}{\rho hc}$ $E = mc\theta$ **and** $m = \pi\rho V$ max temp rise s^{-1} $\left(= \frac{\Delta\theta}{t}\right) = \frac{3 \times 10^{-6}}{1000 \times 5 \times 4200}$ max temp rise $s^{-1} = 1 \times 10^{-13}$ (°C s^{-1})	C1 C1 A1	**Allow** nonstandard letters as long as meaning is clear **Allow** 1000 (kg m^{-3}) for ρ **Allow** $\pi r^2 h$ or $5\pi r^2$ for V **Allow** answer to more than 1s.f. (1.43×10^{-13} (°C s^{-1})) **Examiner's Comments** This too was a complex, multi-stage calculation. Most candidates correctly found their way into the question by writing down the formula $E = mc\Delta\theta$ and realising that they needed to use the formula $\rho = m/V$ in order to calculate the mass. The volume V of the cylindrical tank could be found using V = depth × cross-sectional area. However, although the depth was specified in the question, the cross-sectional area was not. Successful candidates realised that, if the cross-sectional area was not given, then it must cancel out later in the calculation. Some used algebra and called the cross-sectional area A. Others simply made up a value for A (A = 1 m^2 is the easiest).
			Total	**9**	
21		i	Identification from graph of two intensities and corresponding separation between them (x). Correct substitution into $I = I_0 e^{-\mu x}$ and fully correct calculation leading to $\mu = 0.84$ (cm^{-1})	C1 A1	**Note** check value of intensities to ± ½ small square. x missing implies $x = 1$. Graph misread lose all marks. May be seen from substitution into $I = I_0 e^{-\mu x}$. No POT error at this point **Note** I_0 and I must be in correct position in equation, so that ($I < I_0$). If I and I_0 are reversed, μ will be negative. **Penalise** this mark for negative answer, or working that would lead to negative answer. **Penalise** POT error here. **Allow** small range of values around 0.84 for variations in graph readings.

					Examiner's Comments The treatment of the logs was well done here (again, as with 22bi) and most of the candidates chose 0.0 and 1.0 cm to produce their values. The factor of 10^3 in the intensity was not needed for this calculation, so candidates who chose to ignore it (or did not see it) were unlikely to be penalised. The negative sign caused a problem if I and I_0 were reversed and candidates deliberately ignoring it would not score the second mark. There was a common alternative to using the 0.0 and 1.0 cm points where candidates used the "half-thickness" value at approximately 0.83 cm which would produce the same answer. As the graph scale on the vertical axis was simple, values which could have been from a "misread" would not be given further marks. Although readings were taken from a graph in the calculation, several candidates gave their final answer to 1sf despite calculating it correctly throughout.
		ii	$I = 1.3 \times 10^3 / 1300$ $(E = I \times A \times t) = 2.6 = 1300 \times 1.0 \times 10^{-4} \times t$ $t = 20$ (s)	B1 C1 A1	**Allow** a value in the range 1.25 − 1.35 × 10^3. **Allow** ecf from incorrect reading of I at 1.0cm from (b)(i) **Allow** use of value of I from B1 except use of 3000 **POT** error allowed on area if area clearly included in the calculation, or if A included in equation **Note**: use of $I = 1.6 \times 10^3$ leading to $t = 16$ (s) with A included scores 2 marks **Examiner's Comments** Many candidates made a good attempt at this question, however the conversion between cm^2 to m^2 and missing the 10^3 on the intensity reading caused two potential power of ten errors.
		iii	A curve starting at $x = 1.0$cm with initially larger negative gradient at $x = 1.0$ cm Exponential curve	M1 A1	**Must not** have a positive gradient for more than half a square vertically Curve must not touch x-axis or be horizontal for more than 3 small squares **Examiner's Comments** Most candidates appreciated that a larger attenuation coefficient would lead to a line which would lead to a lower intensity than a continuation of the original line. Common (and understandable) errors included the line touching the

					x axis and a continuation of the original line of increasing gradient. Some candidates may have misinterpreted the question as they drew a second line from the (3.0, 0.0) point beneath the original line.
			Total	**7**	
2 2		i	Zero amplitude / displacement / oscillations / movement (at the nodes)	B1	**Allow** minimum or least for zero throughout **Ignore** references to pressure e.g. min/max pressure **Allow** correct answers in terms of pressure gradients **Penalise** incorrect answers in terms of antinodes **Ignore** correct answers in terms of antinodes **<u>Examiner's Comments</u>** Most candidates were able to appreciate that the stationary wave has nodes and antinodes and correctly relate them to the movement of the particles. Candidates were expected to give their responses in terms of the nodes, and responses in terms of the antinodes – such as powder is displaced from the antinodes – does not really answer the question. Several candidates drew a stationary wave on the diagram, with nodes and antinodes at the correct places. As the exemplar below shows, this helps confirm in the candidates mind the variation of the oscillations of the stationary wave. It also helps with subsequent questions; although cannot be given marks itself, candidates are always to be encouraged to make additions to diagrams to help them in supporting their responses.  A candidate drawing on the diagram to assist them to appreciate the vibrations at the nodes and antinodes.
		ii	2 λ = 25 (cm) / λ = 12.5 (cm) *v* = 2720 × 0.125 *v* = 340 (ms^{-1})	C1 C1 A1	**Maximum** one POT error in this question **Special case: one mark only** for bare 340 (ms^{-1}) with no working **Allow** 2 marks for 170 ms^{-1} if calculated from λ = 6.25 (cm) **<u>Examiner's Comments</u>** This question was well answered by most candidates who were able to correctly appreciate that the given distance of 25cm corresponded to two complete wavelengths of the stationary wave. Encouragingly, very few candidates did not make the cm to m conversion. A small number of

					candidates thought that the wavelength was the distance between two nodes resulting in an answer of 170 ms^{-1}. Many candidates structured their responses clearly and were able to explain their reasoning.
		iii	$11f_0 = 2.72\ (\times 10^3)$ or $11/4 \times 12.5 = \lambda_o/4$ **or** $\lambda_o = 1.375$ (m) $f_0 = (340 / 1.375) = 247$ (Hz)	C1 A1	**Allow** length of tube = 0.344 (m) **Allow** 250 (Hz) **Allow** ecf on *v* from (c)(ii). **Examiner's Comments** This proved to be a challenging question and only around one fifth of the candidates were able to score any marks. Most successful candidates appreciated that there were 11 quarter wavelengths of the initial wave in the tube and used this to determine the length of the tube, from which they were able to determine the fundamental wavelength and hence the frequency. There are many potential errors in this question, however a common incorrect response was 680Hz, calculated from treating the wavelength of the fundamental wave as twice the given distance of 25cm.
			Total	**6**	
23			**A**	1	**Examiner's Comments** The vast majority of candidates were able to reach the correct response and appreciated that the intensity of a wave is proportional to the $(\text{amplitude})^2$ as given in the specification point 4.4.1(g). The most common incorrect response was, as expected, C.
			Total	**1**	
24		i	π (rad)	B1	**Allow** 3.14 or 3.1 (rad) **Do not allow** answer in degrees **Examiner's Comments** The first question can generally be expected to be accessible to most candidates and many were able to gain a mark on this. Common errors included π/2 and giving responses in terms of wavelengths. Although there is no requirement to show working for this question, many candidates converted from complete cycles (using wavelengths or 360°) to help them convert to radians.
		ii	− 5.0 (cm)	B1	**Allow** 1 SF. **Must** see negative sign. **Examiner's Comments**

					This proved to be a challenging question; it appears many candidates were unable to appreciate the progressive nature of the wave on a displacement-distance graph. By far the most common response was 0, where it is likely the candidates ignored the inclusion of time and simply gave the displacement at 1.5cm.
			Total	**2**	
25		i	**Any acceptable methods e.g.** Note matched to a note produced by a speaker connected to a variable (calibrated) signal generator/ Reduce background sound level **OR** Count the number of oscillations and divide by time taken (from a stopwatch/oscilloscope/slow motion camera) Take many oscillations e.g. 5 or 10/ longer time **OR** Microphone connected to oscilloscope to measure *T* / period <u>and</u> *f* = 1/*T*/period Reduce background sound level **OR** Use a (calibrated) strobe to determine the frequency Dim down the lights (AW) to get the best results	B1 B1	**Allow** vibration generator connected to a variable (calibrated) signal generator **Allow** Adjust signal generator to the fundamental frequency (when a stationary wave is achieved) **<u>Examiner's Comments</u>** The advance information listed that practical skills would be assessed within topic 4.4 waves, but only some candidates were able to describe a simple method to determine the fundamental frequency of the oscillating wire. Marks were still given for a suitable method for determining the fundamental frequency of any oscillating wire, e.g. using a vibration generator and variable signal generator but few candidates developed their method to describe how they would obtain accurate measurements, e.g. measuring the time for 10 oscillations and then dividing by 10 to find the time period *T*, etc. Candidates may not have had the opportunity to carry out this practical skill independently but they should be familiar with the procedure and how measurements are taken to accurately find the fundamental frequency of a stationary wave. Exemplar 2 The wavelength at the fundamental frequency is 2L, so they could have used speed = wavelength x frequency to find fundamental frequency, as when the wavelength is at 2L the fundamental frequency will appear be shown. The had to do speed/2L to find the fundamental freqy of the wire. It will be the point where there are nodes only at the supports. [2] Exemplar 2 shows a typical middle range response. This response demonstrates a lack of knowledge and understanding of the practical skills required to measure the fundamental frequency as there is no description of a method to measure the time period of a stationary wave.
		ii	**1** 1.24 (m) ($v = f\lambda$) **2** v = 58 × 1.24 v = 72 (m s^{-1}) **3** % uncertainty = [2 × 2.5] + 1.0 + 0.5 (= 6.5)	B1 C1 A1 C1	**Allow** 1.2(m) **<u>Examiner's Comments</u>** Most candidates performed well on this question as they correctly applied that at the fundamental frequency $\lambda = 2L$. Candidates at the lower end did not recall the wavelength

			$0.065 \times [4 \times 58^2 \times 9.7 \times 10^{-4} \times 0.62]$ absolute uncertainty = 0.53 (N)	A1	of the stationary wave in terms of the length of wire. **ECF** from (b)(ii)1 **Examiner's Comments** Nearly 80% of candidates correctly selected and applied the formula $v = f\lambda$. Where candidates had incorrectly determined the wavelength at the fundamental frequency, they were given marks for carrying out a correct calculation using their value. Answer to **2sf** only **Allow ECF** 1 mark for %uncertainty of 4% and absolute uncertainty 0.32N **2sf** **Examiner's Comments** About a third of candidates used the information given in the question to determine the percentage uncertainty of 6.5% and used this to find the absolute uncertainty. Some candidates used the maximum and minimum values of the tension to find the absolute uncertainty. Some candidates correctly calculated a value for the absolute uncertainty but did not give their answer to 2 significant figures as the question requested.
			Total	**7**	
26			B	1	**Examiner's Comments** Candidates performed well on this question as most gave the correct answer B as they correctly selected and applied the equation $I = P/A$.
			Total	**1**	
27			B	1	**Examiner's Comments** Candidates performed well on this question as most gave the correct answer B by recognising that sound is an example of a longitudinal wave and electromagnetic waves are an example of transverse waves but that they can both form stationary waves.
			Total	**1**	
28			C	1	**Examiner's Comments** 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**	

29	a		1.97×10^8 and 2.05×10^8	B1	in that order **Examiner's Comments** This question was well answered with most candidates giving answers correct to three significant figures by using standard form.
	b		$\sin C = \frac{1}{1.52} = 0.658$ 41(°)	C1 A1	41.1395 or 41.3 **Examiner's Comments** Most candidates clearly demonstrated the method to determine the critical angle. Some candidates incorrectly used 45˚ rather than 90˚. **Assessment for learning** To determine the critical angle, the angle of refraction is 90˚ so sin 90˚ = 1.
	c		TIR shown at lower left-hand boundary with ray turned through 90° and horizontally to the lower right-hand boundary (by eye) TIR shown at lower right-hand boundary with ray returning vertically parallel to incident ray (exiting glass block) (by eye)	M1 A1	Candidates needed to realise that the angle of incidence was 45° which was greater than the critical angle. So, the total internal reflection occurs at the first surface. No marks were given for candidates who drew any rays that showed refraction. Candidates who scored the first mark invariably realised that the angle of incidence at the second boundary was also 45˚ so again drew a totally internally reflect ray parallel to the incident ray. Rays should be straight and therefore drawn with a ruler. A significant number of candidates omitted this question.
	d	i	$\sin C = \frac{1.46}{1.52} = 0.961$ 74 (°)	C1 A1	73.8 **Examiner's Comments** Candidates found this question challenging. Good candidates used the two refractive indexes 1.42 and 1.52 correctly. Many candidates incorrectly used an angle of 45˚ or 41˚ rather than 90˚. A significant number of candidates omitted this question.
		ii	Ray bends away from the normal (by eye)	B1	**Note** no ECF from (d)(i) **Examiner's Comments** Candidates often did not draw a refracted ray. Of those

					candidates who gained the answer to the previous part correctly, many did not realise that the ray would bend (slightly) away from the normal. A significant number of candidates omitted this question.
			Total	**8**	