PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 5: WAVES AND PARTICLE NATURE OF LIGHT

INTERFERENCE AND DIFFRACTION

SCORE	PERCENTAGE
/366	%

STEMUP

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Mark Scheme

Q1.

Question Number	Acceptable Answers	Additional guidance	Mark
*	This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. **Indicative Content** • Two waves travelling in opposite directions (1) • Superpose / interfere (1) • Constructive (interference) if waves in phase **Or** Constructive (interference) if path difference = $n\lambda$ (1) • Destructive (interference) if waves in antiphase **Or** destructive (interference) if path difference = $(n + ½)\lambda$ (1) • Nodes are formed from points of destructive (interference) **or** antinodes are formed from points of constructive (interference) (1) • Nodes are points with min amplitude **and** antinodes are points with max amplitude (1)		6

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Q2.

Question Number	Answer	Mark
	D originate from one source	**1**
	Incorrect Answers: A – coherence requires a constant phase difference not necessarily 0 B – planes not relevant C – amplitude not relevant	

Q3.

Question Number	Answer	Mark
(a)	Idea of two or more waves meeting (1) Displacement is sum of individual displacements (1)	2

Question Number	Answer	Mark
(b) (i)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate – e.g. if the term 'superimpose' is used this mark is not awarded) When in phase constructive interference/superposition occurs (1) **Or** when path difference is $n\lambda$ constructive interference/superposition occurs When in antiphase destructive interference/superposition occurs **Or** when path difference is $(n + ½)\lambda$ destructive interference/superposition (1) occurs Light band forms when in phase **Or** path difference is $n\lambda$ **Or** constructive **Or** Dark band forms when in antiphase **Or** path difference is $(n + ½)\lambda$ **Or** (1) destructive	3
(b) (ii)	Oscillations of light from the two filters are perpendicular to each other (1) So there are no opposite components to cancel each other out **Or** so the waves do not interact/interfere (1) So zero amplitude not possible (1) **OR** (If the candidate assumes that it is a source of polarised light) One filter is parallel to the plane of polarisation of the light source, so light is transmitted but the other one absorbs light (1) So light now only reaches the screen from one filter, so there is no interference (1) So zero amplitude not possible (1)	3

Q4.

Question Number	Acceptable Answers	Additional guidance	Mark
(i)	An explanation that makes reference to the following: • Path lengths (A-O and B-O) are equal **Or** Path difference is zero (1) • Will arrive in phase **Or** phase difference is zero (1) • (Bright line is position of) constructive interference/superposition (1)		3
(ii)	• 600 nm **Or** 600×10^{-9} m **Or** 6.0×10^{-7} m **Or** one wavelength **Or** λ (1)	Do not accept ($n\lambda$) Accept any correct equivalent value	1

Q5.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	An explanation that makes reference to: • waves/light passing through a narrow gap spread/s out **(1)** • light reaches the wall from each part of the slit with differing phase relationships **(1) OR** light reaches the wall from each part of the slit with differing path lengths **(1)** • when the waves meet superposition takes place and if the waves are in antiphase it results in destructive interference so a dark spot is seen **(1) OR** when the waves meet superposition takes place and if the waves are in phase it results in constructive interference so a bright(er) region is seen **(1)**	Accept relevant reference to Huygen's construction for first mark.	**3**
(b)	An explanation that makes reference to: • green light has a shorter wavelength than red light **(1)** **OR** red light has a longer wavelength that green light **(1)** • so green light diffracts less than red light **or** red light diffracts more than green light **(1)** • so the dark points would be closer to the centre or more dark points would be seen in the same space on the wall or central fringe narrower **(1)**	Accept a diagram clearly to the same scale and showing a narrowed pattern. MP2 and MP3 may be awarded if reference is made to frequency difference rather than wavelength.	**3**
(c)	• use of trigonometrical functions to calculate θ **(1)** • calculate diffraction grating spacing **(1)** • wavelength = 5.1×10^{-7} m **(1)**	Example of calculation: $\theta = \tan^{-1}(0.23\text{ m}/1.5\text{ m}) = 8.7°$ $d = 10^{-3}/300 = 3.3 \times 10^{-6}$ m $\lambda = 3.3 \times 10^{-6}$ m $\times \sin 8.7°$ $= 5.1 \times 10^{-7}$ m	**3**

Q6.

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Question Number	Acceptable Answer	Additional Guidance	Mark
* (continued)	**Indicative content** • Analyses and interprets the text to conclude that diffraction occurs when light is reflected from the CD surface • Each ring on the CD acts as a diffraction centre scattering light in all directions • Interference occurs (superposition of light from the multiple light sources) • In directions in which there is a phase difference equal to an even multiple of π rad constructive interference (reinforcement) occurs **OR** in directions in which there is a path difference equal to a whole number of wavelengths constructive interference (reinforcement) occurs • White light is a range (mixture) of wavelengths • Hence each wavelength of light reinforces in a different direction which explains why a spectrum is seen		**6**

Q7.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Coherent waves have a constant phase relationship	(1)	MP2-4: accept wavelength for frequency	**4**
	• Coherent waves have the same frequency	(1)		
	• However, for each frequency present the (two) reflected waves are coherent	(1)	MP4: hence with a white light source you would see a set of coloured rings	
	• Hence with a non-monochromatic source, a set of dark rings for each frequency would be produced	(1)		

Q8.

Question Number	Answer	Mark
	A $\frac{2\pi t}{T}$	1
	Incorrect Answers: B – no factor of 2 C – incorrect substitution of f D – incorrect substitution of f and no factor of 2	

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $E_K = p^2 / 2m$ (1) • Use of $\lambda = h/p$ (1) • $\lambda = 5.0 \times 10^{-11}$ (m) calculated from E_K (1) **Or** $E_K = 9.7 \times 10^{-17}$ (J) calculated fro $\lambda = 5.0 \times 10^{-11}$ m **Or** $p = 1.3 \times 10^{-23}$ (kg m s^{-1}) calculated from E_K **and** $p = 1.3 \times 10^{-23}$ (kg m s^{-1}) calculated from $\lambda = 5.0 \times 10^{-11}$ m • path difference at X is $\lambda/2$ (1) **Or** path difference at Y is λ • (electron) <u>waves</u> at X are in antiphase (1) **Or** (electron) <u>waves</u> at Y are in phase • at X destructive interference/superposition takes place (1) **Or** at Y constructive interference/superposition takes place	MP1 accept use of $p = mv$ **and** Use of $E_k = ½ mv^2$ MP4 accept (n + ½) λ or n λ respectively <u>Example of calculation</u> $p = \sqrt{(2 \times 9.11 \times 10^{-31}\text{ kg} \times 9.6 \times 10^{-17}\text{ J})}$ $p = 1.32 \times 10^{-23}$ kg m s^{-1} $\lambda = 6.63 \times 10^{-34}$ Js / 1.32×10^{-23} kg m s^{-1} $\lambda = 5.0 \times 10^{-11}$ m	6

Q10.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	**Either** • Use of $n = \frac{c}{v}$ (1) • Use of $v = f\lambda$ (with v in coating) (1) • Use of path difference $= \frac{\lambda}{2}$ with factor of 2 (1) • $d = 9.1 \times 10^{-8}$ m (1) **OR** • Use of $v = f\lambda$ (with c in air) • Use of $n = \frac{\lambda_{air}}{\lambda_{coating}}$ • Use of path difference $= \frac{\lambda}{2}$ with factor of 2 $d = 9.1 \times 10^{-8}$ m	Example of calculation: $v = \frac{3.00 \times 10^{8}\ \text{m s}^{-1}}{1.38} = 2.17 \times 10^{8}\ \text{m s}^{-1}$ $\lambda = \frac{2.17 \times 10^{8}\ \text{m s}^{-1}}{6.00 \times 10^{14}\ \text{Hz}} = 3.62 \times 10^{-7}\ \text{m}$ $d = \frac{\lambda}{4} = \frac{3.62 \times 10^{-7}\ \text{m}}{4} = 9.06 \times 10^{-8}\ \text{m}$	4

Question Number	Acceptable answers	Additional guidance	Mark
(ii)	• Red and blue light do not interfere destructively, so remain in the reflected light **Or** If green light is cancelled/eliminated, then red and blue light will remain in the reflected light. (1)		1

Q11.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• use of strain = extension / length (1) • change in length = 4.8×10^{-18} (m) **Or** max strain for $0.001\times$ proton size = 2.2×10^{-22} (1) • comparison of their change in length to 8.8×10^{-19}(m) **Or** comparison of their max strain to 1.2×10^{-21} (1)	Example of calculation Change in length = $1.2 \times 10^{-21} \times 4000$ m = 4.8×10^{-18} m Fraction of proton diameter = 4.8×10^{-18} m ÷ 8.8×10^{-16} m = 0.0055	3

Question Number	Acceptable answers	Additional guidance	Mark
(ii)	• half wavelength path difference means waves in antiphase **(1)** • so destructive interference takes place **(1)** • this results in zero amplitude, (so no signal detected) **(1)** • a change in length will result in a change in path difference, so signal detected **(1)** **Or** a change in length will result in a change in phase difference, so signal detected	Do not accept 'out of phase' for MP1 Accept reference to being 'not out of phase' for MP4	**4**

Question Number	Acceptable answers	Additional guidance	Mark
(iii)	• if initially the path difference is zero there will be a maximum signal **(1)** • a change from max amplitude would represent a much smaller percentage (therefore less sensitive) **(1)**	MP2 alternative: a change from minimum amplitude would represent a much larger percentage (therefore more sensitive) MP2 Accept 'it is easier to detect the change from no light to light' MP2 Accept suitable reference to uncertainty	**2**

Q12.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	An explanation that makes reference to the following: • The light is diffracted **(1)** • (because) each point on wavefront acts as a source of secondary waves **Or** wavelets emitted (from points on the wavefront) **(1)**	Marks may be shown on a clearly labelled diagram	**2**

Question Number	Acceptable answers	Additional guidance	Mark
(b)	An explanation that makes reference to the following: • Path lengths (to centre of shadow from edge of ball) are equal **(1)** **Or** path difference (at spot) is zero • Will arrive in phase **Or** phase difference is zero **(1)** • (Bright spot is position of) constructive interference/superposition **(1)**		**3**

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Q13.

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(6)

Indicative content

- the progressive waves are reflected and two waves travelling in opposite directions meet
- superposition/interference takes place
- where the waves are in phase, it is constructive, forming antinodes
- where the waves are in antiphase, it is destructive, forming nodes
- antinodes are points of maximum amplitude, so water will not remain at antinodes
- nodes are points of zero displacement, so water can stay at these points

Q14.

Question Number	Answer	Mark
*(a)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) The waves superpose **Or** diffraction at the double slits **(1)** Where they are in phase **Or** when path difference is a whole number of wavelengths constructive interference takes place **(1)** Where they are in antiphase / when path difference is an odd number of half wavelengths destructive interference takes place **(1)** Bright bands are when waves are in phase / when path difference is nλ / constructive interference **Or** reverse for dark bands **(1)**	**4**
(b)	coherent = constant phase relationship/difference (between light arriving from the two sources) **Or** if they are not coherent the phase relationship/difference will vary. **(1)** The idea that at a given point there would sometimes be constructive interference and sometimes destructive interference etc **(1)**	**2**
(c)	Interference (accept diffraction) only occurs with waves. **(1)**	**1**
	Total for question	**7**

Q15.

Question Number	Acceptable Answers	Additional guidance	Mark
	• Waves (from gaps) superpose/interference **(1)** • Constructive (interference) when waves are in phase **Or** path difference is nλ **(1)** • Destructive (interference) when waves are in antiphase **Or** path difference is $(n+\frac{1}{2})\lambda$ **(1)** • Links constructive interference to maximum intensity **Or** links desructive interference with minimum/zero intensity **(1)**	Not superimpose MP3 Do not accept out of phase	**4**

Q16.

Question Number	Answers	Additional Guidance	Mark
	D	have the same frequency	**(1)**

Q17.

Question Number	Acceptable Answers	Additional guidance	Mark
	• Line/surface joining points on a wave that are in phase (1)		1

Q18.

Question Number	Acceptable answers	Additional guidance	Mark
	• Wave and reflection will meet (1) • Superposition / interference occurs (1) • Where in antiphase, destructive interference (1) • Zero/minimum amplitude at nodes – so mice won't hear (1) **Either** • But node separation = ½ wavelength = (about) 7 mm (1) • Too small a space for a mouse to avoid the ultrasound, so suggestion not correct (1) **Or** (MP5 and 6) • Wall absorbs some ultrasound so reflected wave has smaller amplitude than incident wave (1) • Incomplete cancellation, some ultrasound even at nodes, so suggestion (probably) incorrect (1) **Or** (MP5 and 6) • Waves also arrive from other walls/floor/ceiling/multiple reflection (1) • Complete cancellation unlikely so suggestion (probably) incorrect (1) **Or** (MP5 and 6) • A standing wave will only be formed if the length of the room is a whole number of half wavelengths (1) • Otherwise there will be no nodes so no silent spots where the mouse won't hear (1)	Example of calculation $\lambda/2 = 0.013$ m / 2 = 0.0065 m	6

Q19.

Question Number	Answer		Mark
(a)	Calculates path difference = 12 (cm) Phase difference 0, 360° or 2π **Or** Calculates number of wavelengths in two paths Phase difference 0, 360° or 2π	(1) (1) (1) (1)	**2**
(b)	Waves superpose **Or** interference between two waves takes place In phase constructive **Or** Antiphase destructive Links to <u>amplitude</u> maximum **Or** <u>amplitude</u> zero respectively In phase/constructive/max amplitude is where chocolate is hot with opposite at cold spots. **Or** Antiphase/destructive/min amplitude is where chocolate is cold with opposite at hot spots.	(1) (1) (1) (1)	**4**
(c)	Coherent means a constant phase relationship (If the relationship not constant) a point could sometimes be constructive and sometimes destructive	(1) (1)	**2**
(d)	Use of $c = f\lambda$ Calculates $c = 2.94 \times 10^8$ (m s^{-1}) **Or** $\lambda = 12.2$ (cm) **Or** $f = 2500$ (MHz) Sensible comment based on their calculated value. e.g. close to real value, so successful **Or** reference to uncertainty in data <u>Example of calculation</u> $c = 2.45 \times 10^9$ Hz $\times$ 0.12 m $c = 2.94 \times 10^8$ m s^{-1}	(1) (1) (1)	**3**
	Total for question		**11**

Q20.

Question Number	Acceptable Answers	Additional Guidance	Mark
	An explanation that makes reference to: • coherent means there is a constant phase relationship **(1)** • for some parts of the beam the phase difference could be 180°/in antiphase **(1)** • causing destructive interference and therefore zero amplitude **(1)**		**3**

Q21.

Question Number	Answer	Mark
	C $\frac{\pi}{3}$	**1**
	Incorrect Answers: **A** – incorrect **B** – incorrect **D** – incorrect	

Q22.

Question Number	Acceptable answers	Additional guidance	Mark
	D 90 degrees		**1**

Q23.

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Question Number	Acceptable answers	Additional guidance	Mark
* (continued)	**Indicative content** • Sound waves incident upon surfaces within the concert hall will be reflected. • Some frequencies will arrive from different directions with a phase difference of (any odd multiple of) π radians **(1) OR** path difference is odd number of half wavelengths • Destructive superposition/interference will occur, causing the waves with those frequencies to be quieter than others. • Other frequencies arrive with a phase difference of zero or (any multiple of) 2π radians **(1) OR** a whole number of wavelengths • Constructive superposition/interference will occur, causing waves with those frequencies to be louder than others. • Problem arises due to reflections from walls, so use absorbing material on surfaces to reduce reflections.		**6**

Question Number	Acceptable answers	Additional guidance	Mark
* (continued)	**Alternative approach based on standing waves:** • Sound waves incident upon surfaces within the concert hall will be reflected. • Reflections from walls set up standing waves (in room) • Nodes and antinodes are formed for certain frequencies of sound • Nodes are areas of zero/low amplitude so the frequencies of those sound waves will be quieter than others • Antinodes are areas of maximum amplitude so the frequencies of these sound waves will be louder than others • Problem arises due to reflections from walls, so use absorbing material on surfaces to reduce reflections		

Q24.

Question Number	Acceptable Answers		Additional Guidance	Mark
(i)	• Pendulum A is π/2 ahead of pendulum B	(1)		1
(ii)	• $T = 1.2$ s from graph • Use of $T = 2\pi\sqrt{(l/g)}$ • $l = 0.36$ m	(1) (1) (1)	$T = 3.0$ s / 2.5 oscillations 1.2 s = $2\pi\sqrt{(l/9.81\ \text{N kg}^{-1})}$ $l = 0.36$ m	3

Q25.

Question Number	Answer	Mark
	C	**1**

Q26.

Question Number	Acceptable Answers		Additional guidance	Mark
(i)	• Amplitude/energy/intensity of the soundwave reduces with distance travelled • Appreciate that at A **or** B two waves are interfering destructively **Or** at A **and** B there are nodes • at B the waves have travelled similar distances so have similar amplitudes	**(1)** **(1)** **(1)**	Assume they are talking about point B unless stated otherwise For MP3 Accept answers with respect to waves at point A having different amplitudes due to different distances	**3**

Question Number	Acceptable Answers		Additional guidance	Mark
(ii)	• Uses graph to identify $\lambda =$ 0.16 (m) • Use of $v = f\lambda$ with a valid value from the graph • v =320 m s^{-1}	**(1)** **(1)** **(1)**	using $\lambda = 0.08$ gives v= 160 m s^{-1} MP2 only Example of Calculation $v = 2000$ Hz $\times$ 0.16 m = 320 m s^{-1}	**3**

Q27.

Question Number	Answer		Mark
(a)	(sound waves travel as) longitudinal waves **Or** (Air molecules) vibrate parallel to direction of travel of wave	(1)	
	(sound waves travel as) a series of compressions **and** rarefactions **Or** (sound waves travel as) areas of high and low pressure	(1)	
	The idea that these vibrations create a pressure/force/stress/strain on the film **Or** The idea that these compressions/rarefactions create a pressure/force/stress/strain on the film	(1)	
	This pressure/force/stress/strain generates a potential difference (accept idea that vibration/pressure/force/stress/strain causes redistribution of charge within crystal)	(1)	**4**
(b)	Thin film is flexible / lightweight	(1)	
	The idea that there is not much energy in sound	(1)	
	Large area gathers more sound (energy) **Or** Large area generates more power/current/pd	(1)	**3**
(c)	Use of $P=E/t$ with any time, energy in J or kJ Conversion of kJ→J **and** correct time in s (36000 s) P =0.56 W (accept J s^{-1}) <u>Example of calculation</u> Power = 20000 J / 10 × 3600 s Power = 0.56 W	(1) (1) (1)	**3**
(d)	**ONE** *Disadvantage* Expensive, Not washable Only works with (loud) noise Long time to charge a phone Low output power	(1)	
	ONE *Advantage* Free source of energy Lower/zero running cost Portable Can be used when away from mains electricity	(1)	**2**
	[Credit should be given for any reasonable correct physics point but not for generalised comments such as 'good for the planet' 'environmentally friendly']		

Q28.

Question Number	Answer	Additional Guidance	Mark
	• use of $v = f\lambda$ (1) • Path difference needs to be $= \left(n + \frac{1}{2}\right)\lambda$ **Or** Path difference needs to be $\frac{\lambda}{2}$ **Or** Length of chamber needs to be $\frac{\lambda}{4}$ (1) **Or** (1) See $\frac{2.4\text{ m}}{4}$ (1) • (so) waves meet in antiphase • destructive interference	Example of calculation $\lambda = \frac{340\text{ m s}^{-1}}{140\text{ s}^{-1}} = 2.43\text{ m}$ path difference $= 2l = \frac{2.43\text{ m}}{2}$ $l = \frac{2.43\text{ m}}{4} = 0.61\text{ m}$	**4**

Q29.

Question Number	Acceptable Answers	Additional guidance	Mark
	• Interference of soundwaves occurs in the tube (1) • (and a) stationary wave is formed **Or** nodes **and** antinodes are formed (1) • (where) constructive interference occurs the amplitude is maximum **Or** at antinodes the amplitude is maximum (1) • (where) destructive interference occurs the amplitude is zero/minimum **Or** at nodes the amplitude is zero/minimum (1) • Powder is displaced from points of max amplitude to min amplitude points **Or** Powder is displaced from antinode to nodes (1)		**5**

Q30.

Question Number	Answer	Mark
	B $2\pi tf$	**1**
	Incorrect Answers: A – incorrect expression C– incorrect expression D – incorrect expression	

Mark Scheme

Q1.

Question Number	Acceptable Answers	Additional guidance	Mark
*	This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. **Indicative Content** • Two waves travelling in opposite directions (1) • Superpose / interfere (1) • Constructive (interference) if waves in phase **Or** Constructive (interference) if path difference = $n\lambda$ (1) • Destructive (interference) if waves in antiphase **Or** destructive (interference) if path difference = $(n + ½)\lambda$ (1) • Nodes are formed from points of destructive (interference) **or** antinodes are formed from points of constructive (interference) (1) • Nodes are points with min amplitude **and** antinodes are points with max amplitude (1)		**6**

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Q2.

Question Number	Answer	Mark
(a)	Idea of two or more waves meeting **(1)** Displacement is sum of individual displacements **(1)**	**2**

Question Number	Answer		Mark
(b) (i)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate – e.g. if the term 'superimpose' is used this mark is not awarded)		
	When in phase constructive interference/superposition occurs **Or** when path difference is $n\lambda$ constructive interference/superposition occurs	**(1)**	
	When in antiphase destructive interference/superposition occurs **Or** when path difference is $(n + ½) \lambda$ destructive interference/superposition occurs	**(1)**	
	Light band forms when in phase **Or** path difference is $n\lambda$ **Or** constructive **Or** Dark band forms when in antiphase **Or** path difference is $(n + ½) \lambda$ **Or** destructive	**(1)**	**3**
(b) (ii)	Oscillations of light from the two filters are perpendicular to each other	**(1)**	
	So there are no opposite components to cancel each other out **Or** so the waves do not interact/interfere	**(1)**	
	So zero amplitude not possible	**(1)**	
	OR (If the candidate assumes that it is a source of polarised light) One filter is parallel to the plane of polarisation of the light source, so light is transmitted but the other one absorbs light	**(1)**	
	So light now only reaches the screen from one filter, so there is no interference	**(1)**	
	So zero amplitude not possible	**(1)**	**3**

Q3.

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Question Number	Acceptable Answer	Additional Guidance	Mark
* (continued)	**Indicative content** • Analyses and interprets the text to conclude that diffraction occurs when light is reflected from the CD surface • Each ring on the CD acts as a diffraction centre scattering light in all directions • Interference occurs (superposition of light from the multiple light sources) • In directions in which there is a phase difference equal to an even multiple of π rad constructive interference (reinforcement) occurs **OR** in directions in which there is a path difference equal to a whole number of wavelengths constructive interference (reinforcement) occurs • White light is a range (mixture) of wavelengths • Hence each wavelength of light reinforces in a different direction which explains why a spectrum is seen		**6**

Q4.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• use of strain = extension / length	**(1)**	Example of calculation Change in length = $1.2 \times 10^{-21} \times 4000$ m = 4.8×10^{-18} m Fraction of proton diameter = 4.8×10^{-18} m ÷ 8.8×10^{-16} m = 0.0055	**3**
	• change in length = 4.8×10^{-18} (m) **Or** max strain for 0.001× proton size = 2.2×10^{-22}	**(1)**		
	• comparison of their change in length to 8.8×10^{-19}(m) **Or** comparison of their max strain to 1.2×10^{-21}	**(1)**		

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• half wavelength path difference means waves in antiphase	**(1)**	Do not accept 'out of phase' for MP1	**4**
	• so destructive interference takes place	**(1)**		
	• this results in zero amplitude, (so no signal detected)	**(1)**		
	• a change in length will result in a change in path difference, so signal detected **Or** a change in length will result in a change in phase difference, so signal detected	**(1)**	Accept reference to being 'not out of phase' for MP4	

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Question Number	Acceptable answers	Additional guidance	Mark
(iii)	• if initially the path difference is zero there will be a maximum signal (1) • a change from max amplitude would represent a much smaller percentage (therefore less sensitive) (1)	MP2 alternative: a change from minimum amplitude would represent a much larger percentage (therefore more sensitive) MP2 Accept 'it is easier to detect the change from no light to light' MP2 Accept suitable reference to uncertainty	2

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	An explanation that makes reference to the following: • The light is diffracted (1) • (because) each point on wavefront acts as a source of secondary waves **Or** wavelets emitted (from points on the wavefront) (1)	Marks may be shown on a clearly labelled diagram	2

Question Number	Acceptable answers	Additional guidance	Mark
(b)	An explanation that makes reference to the following: • Path lengths (to centre of shadow from edge of ball) are equal (1) **Or** path difference (at spot) is zero • Will arrive in phase **Or** phase difference is zero (1) • (Bright spot is position of) constructive interference/superposition (1)		3

Q6.

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	Indicative content • the progressive waves are reflected and two waves travelling in opposite directions meet • superposition/interference takes place • where the waves are in phase, it is constructive, forming antinodes • where the waves are in antiphase, it is destructive, forming nodes • antinodes are points of maximum amplitude, so water will not remain at antinodes • nodes are points of zero displacement, so water can stay at these points		

Q7.

Question Number	Answer	Mark
*(a)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) The waves superpose **Or** diffraction at the double slits **(1)** Where they are in phase **Or** when path difference is a whole number of wavelengths constructive interference takes place **(1)** Where they are in antiphase / when path difference is an odd number of half wavelengths destructive interference takes place **(1)** Bright bands are when waves are in phase / when path difference is $n\lambda$ / constructive interference **Or** reverse for dark bands **(1)**	**4**
(b)	coherent = constant phase relationship/difference (between light arriving from the two sources) **Or** if they are not coherent the phase relationship/difference will vary. **(1)** The idea that at a given point there would sometimes be constructive interference and sometimes destructive interference etc **(1)**	**2**
(c)	Interference (accept diffraction) only occurs with waves. **(1)**	**1**
	Total for question	**7**

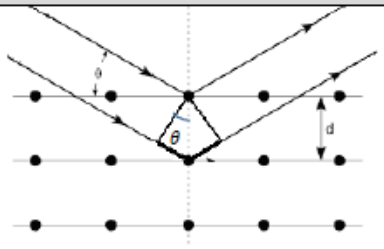
Q8.

Question Number	Answer	Additional guidance	Mark
	B	(λ / 2)	**(1)**

Q9.

Question Number	Acceptable answers		Additional guidance	Mark
	• Wave and reflection will meet	(1)	Example of calculation $\lambda/2 = 0.013 \text{ m} / 2$ $= 0.0065 \text{ m}$	6
	• Superposition / interference occurs	(1)		
	• Where in antiphase, destructive interference	(1)		
	• Zero/minimum amplitude at nodes – so mice won't hear	(1)		
	Either			
	• But node separation = ½ wavelength = (about) 7 mm	(1)		
	• Too small a space for a mouse to avoid the ultrasound, so suggestion not correct	(1)		
	Or (MP5 and 6)			
	• Wall absorbs some ultrasound so reflected wave has smaller amplitude than incident wave	(1)		
	• Incomplete cancellation, some ultrasound even at nodes, so suggestion (probably) incorrect	(1)		
	Or (MP5 and 6)			
	• Waves also arrive from other walls/floor/ceiling/multiple reflection	(1)		
	• Complete cancellation unlikely so suggestion (probably) incorrect	(1)		
	Or (MP5 and 6)			
	• A standing wave will only be formed if the length of the room is a whole number of half wavelengths	(1)		
	• Otherwise there will be no nodes so no silent spots where the mouse won't hear	(1)		

Q10.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Identification of θ between a wavefront and a vertical line • Clear evidence of extra distance before **and** after reflection	(1) (1)		2

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• There is more than one order (of diffraction)	(1)	Accept: path difference of one λ for 1st ring and 2 λ for 2nd ring rings occur for any whole number of wavelengths each ring corresponds to a different layer of atoms from which the electrons reflect.	1

Q11.

Question Number	Answer	Mark
	C	1

Q12.

Question Number	Answer		Mark
(a)	Calculates path difference = 12 (cm) Phase difference 0, 360° or 2π **Or** Calculates number of wavelengths in two paths Phase difference 0, 360° or 2π	(1) (1) (1) (1)	2
(b)	Waves superpose **Or** interference between two waves takes place In phase constructive **Or** Antiphase destructive Links to amplitude maximum **Or** amplitude zero respectively In phase/constructive/max amplitude is where chocolate is hot with opposite at cold spots. **Or** Antiphase/destructive/min amplitude is where chocolate is cold with opposite at hot spots.	(1) (1) (1) (1)	4
(c)	Coherent means a constant phase relationship (If the relationship not constant) a point could sometimes be constructive and sometimes destructive	(1) (1)	2
(d)	Use of $c = f\lambda$ Calculates $c = 2.94 \times 10^8$ (m s^{-1}) **Or** $\lambda = 12.2$ (cm) **Or** $f = 2500$ (MHz) Sensible comment based on their calculated value. e.g. close to real value, so successful **Or** reference to uncertainty in data Example of calculation $c = 2.45 \times 10^9$ Hz $\times$ 0.12 m $c = 2.94 \times 10^8$ m s^{-1}	(1) (1) (1)	3
	Total for question		11

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
	D 90 degrees		1

Q14.

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Question Number	Acceptable answers	Additional guidance	Mark
* (continued)	**Indicative content** • Sound waves incident upon surfaces within the concert hall will be reflected. • Some frequencies will arrive from different directions with a phase difference of (any odd multiple of) π radians **(1) OR** path difference is odd number of half wavelengths • Destructive superposition/interference will occur, causing the waves with those frequencies to be quieter than others. • Other frequencies arrive with a phase difference of zero or (any multiple of) 2π radians **(1) OR** a whole number of wavelengths • Constructive superposition/interference will occur, causing waves with those frequencies to be louder than others. • Problem arises due to reflections from walls, so use absorbing material on surfaces to reduce reflections.		**6**

Question Number	Acceptable answers	Additional guidance	Mark
* (continued)	**Alternative approach based on standing waves:** • Sound waves incident upon surfaces within the concert hall will be reflected. • Reflections from walls set up standing waves (in room) • Nodes and antinodes are formed for certain frequencies of sound • Nodes are areas of zero/low amplitude so the frequencies of those sound waves will be quieter than others • Antinodes are areas of maximum amplitude so the frequencies of these sound waves will be louder than others • Problem arises due to reflections from walls, so use absorbing material on surfaces to reduce reflections		

Q15.

Question Number	Answer	Mark
	D	1

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Q16.

Question Number	Answer	Mark
	B	1

Q17.

Question Number	Answer	Additional Guidance	Mark
	• use of $v = f\lambda$ (1) • Path difference needs to be $= \left(n + \frac{1}{2}\right)\lambda$ **Or** Path difference needs to be $\frac{\lambda}{2}$ **Or** Length of chamber needs to be $\frac{\lambda}{4}$ (1) **Or** (1) See $\frac{2.4\text{ m}}{4}$ (1) • (so) waves meet in antiphase • destructive interference	Example of calculation $\lambda = \frac{340\text{ m s}^{-1}}{140\text{ s}^{-1}} = 2.43\text{ m}$ path difference $= 2l = \frac{2.43\text{ m}}{2}$ $l = \frac{2.43\text{ m}}{4} = 0.61\text{ m}$	4

Q18.

Question Number	Acceptable Answers	Additional guidance	Mark
	• Interference of soundwaves occurs in the tube (1) • (and a) stationary wave is formed **Or** nodes **and** antinodes are formed (1) • (where) constructive interference occurs the amplitude is maximum **Or** at antinodes the amplitude is maximum (1) • (where) destructive interference occurs the amplitude is zero/minimum **Or** at nodes the amplitude is zero/minimum (1) • Powder is displaced from points of max amplitude to min amplitude points **Or** Powder is displaced from antinode to nodes (1)		5

Q19.

Question Number	Acceptable answers	Additional guidance	Mark
	• Waves are reflected at ends of strings (1) • The reflected waves meet and superpose/interfere (1) • Where they meet in phase constructive interference takes place producing points of maximum amplitude **Or** Where they meet in phase constructive interference takes place producing antinodes **Or** Where they meet in antiphase destructive interference takes place producing points of zero/minimum amplitude **Or** Where they meet in antiphase destructive interference takes place producing nodes (1)		3

Q20.

Question Number	Answer	Mark
	A	**1**

Mark Scheme

Q1.

Question Number	Acceptable Answers	Additional guidance	Mark
	Either • The wavelength of the electron is less than the wavelength of light (1) (1) • (So) less diffraction (with the electron beam) **Or** (1) • The wavelength of the light is greater than the wavelength of the electrons (1) • (So) more diffraction (with light beam)		**2**

Q2.

Question Number	Answer	Mark
	A	**1**

Q3.

Question Number	Answer	Mark
(a)	Human body contains water molecules **Or** body has same structure as food **(1)** So cells/tissues would gain internal energy **(1)** (Accept cells/tissues would be heated)	**2**
(b) (i)	Waves spread out **(1)** After passing through a gap **Or** after passing around an obstacle **(1)**	**2**
(b)(ii)	Use of $c = f\lambda$ with $c = 3.0 \times 10^8$ m s^{-1} **(1)** $\lambda = 0.12$ m **(1)** Example of calculation $\lambda = 3.0 \times 10^8$ m s$^{-1} \div 2.5 \times 10^9$ Hz $\lambda = 0.12$ m	**2**
(b)(iii)	Diameter = 2mm **(1)**	**1**
***(b)(iv)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Diffraction greatest when wavelength is about the same as gap size **(1)** Diameter of holes much greater than wavelength of light **and** diameter of holes less than microwave wavelength **(1)** so no/little diffraction of light takes place **Or** so microwave radiation still diffracted through large angle but intensity is very small. **(1)** MP3 must follow on from relevant part of MP2	**3**

Q4.

Question Number	Acceptable Answers	Additional Guidance	Mark
	A		1

Q5.

Question Number	Answers	Mark
	The only correct answer is B ***A*** *is incorrect because amplitude does not affect the diffraction effect* ***C*** *is incorrect because frequency affects the wavelength and hence the diffraction effect* ***D*** *is incorrect because the speed of sound affects the wavelength and hence the diffraction effect*	1

Q6.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	An explanation that makes reference to: • waves/light passing through a narrow gap spread/s out **(1)** • light reaches the wall from each part of the slit with differing phase relationships **(1) OR** light reaches the wall from each part of the slit with differing path lengths **(1)** • when the waves meet superposition takes place and if the waves are in antiphase it results in destructive interference so a dark spot is seen **(1) OR** when the waves meet superposition takes place and if the waves are in phase it results in constructive interference so a bright(er) region is seen **(1)**	Accept relevant reference to Huygen's construction for first mark.	**3**
(b)	An explanation that makes reference to: • green light has a shorter wavelength than red light **(1)** **OR** red light has a longer wavelength that green light **(1)** • so green light diffracts less than red light **or** red light diffracts more than green light **(1)** • so the dark points would be closer to the centre or more dark points would be seen in the same space on the wall or central fringe narrower **(1)**	Accept a diagram clearly to the same scale and showing a narrowed pattern. MP2 and MP3 may be awarded if reference is made to frequency difference rather than wavelength.	**3**
(c)	• use of trigonometrical functions to calculate θ **(1)** • calculate diffraction grating spacing **(1)** • wavelength = 5.1×10^{-7} m **(1)**	Example of calculation: $\theta = \tan^{-1}(0.23\text{ m}/1.5\text{ m}) = 8.7°$ $d = 10^{-3}/300 = 3.3 \times 10^{-6}$ m $\lambda = 3.3 \times 10^{-6}$ m $\times \sin 8.7°$ $= 5.1 \times 10^{-7}$ m	**3**

Q7.

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Q8.

Question Number	Answer		Mark
(a)	Photon – quantum/packet of something relevant e.g. light, radiation, any other named e-m radiation, energy (quantum/packet) of <u>electromagnetic</u> energy/radiation/waves (dependent mark)	**(1)** **(1)**	**2**
(b)	Use of $(20.66 - 18.70) \times 1.6 \times 10^{-19}$ Use of $E = hf$ (with energy in eV or J) $f = 4.7 \times 10^{14}$ Hz <u>Example of calculation</u> $f = (20.66 - 18.70) \times 1.6 \times 10^{-19} \ / \ 6.63 \times 10^{-34}$ $f = 4.73 \times 10^{14}$ Hz	**(1)** **(1)** **(1)**	**3**
(c)	From kinetic energy of atoms	**(1)**	**1**
(d)	Diffraction Light spreads (sideways) as it passes through the slit Narrower slit causes more diffraction/spreading **Or** diffraction increasing as gap width gets closer to wavelength	**(1)** **(1)** **(1)**	**3**
	Total for question		**9**

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	An explanation that makes reference to the following: • The light is diffracted (1) • (because) each point on wavefront acts as a source of secondary waves **Or** wavelets emitted (from points on the wavefront) (1)	Marks may be shown on a clearly labelled diagram	2

Question Number	Acceptable answers	Additional guidance	Mark
(b)	An explanation that makes reference to the following: • Path lengths (to centre of shadow from edge of ball) are equal (1) **Or** path difference (at spot) is zero • Will arrive in phase **Or** phase difference is zero (1) • (Bright spot is position of) constructive interference/superposition (1)		3

Q10.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• The wave spreads out (after passing through a gap) (1) • Each point on the wave acts as a source of (secondary) wavelets (1) • That interfere/superpose (1)		3

Mark Scheme

Q1.

<table>
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<tr><td></td><td>A Using $n\lambda = d\sin\theta$

<table><tr><th>Number of slits per mm in the diffraction grating</th><th>Wavelength of the light source</th></tr><tr><td>Increased</td><td>Increased</td></tr></table></td><td>1</td></tr>
<tr><td></td><td>Incorrect Answers:
B – wavelength decreasing would cause d to decrease
C – number of slits/mm decreasing would cause d to decrease
D –both decreasing causes d to decrease</td><td></td></tr>
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Q2.

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<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td></td><td>• Use of $d = 1$ / no of slits per metre (1)
• Use of $n\lambda = d \sin\theta$ (1)
• $\theta = 21°$ (1)</td><td><u>Example of calculation</u>
$d = 1 / 600\,000 = 1.67 \times 10^{-6}$ m^{-1}
$n = 1$
6.1×10^{-7} m $= 1.67 \times 10^{-6}$ m^{-1} sin θ
$\theta = 21.47°$</td><td>3</td></tr>
</table>

Q3.

Question Number	Answer	Additional Guidance	Mark
	• calculates $\theta = 24°$ **and** $d = 3.3 \times 10^{-6}$ m • use of $n\lambda = d\sin\theta$ • $6.7 - 6.8 \times 10^{-7}$ m	Example of calculation $\tan\theta = \frac{0.89\text{ m}}{2.0\text{ m}} \quad \theta = 24°$ $d = \frac{1\times10^{-3}}{300} = 3.3 \times 10^{-6}$ m $\lambda = \frac{3.3\times10^{-6}\text{ m} \times \sin 24}{2} = 678$ nm	3

Q4.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Use of trigonometry to determine θ • Calculation of both angles • Use of $d\sin\theta = n\lambda_1$ to calculate d • Use of $d\sin\theta = n\lambda_2$ with d • $\lambda_2 = 5.3 \times 10^{-7}$ m (530 nm)	(1) (1) (1) (1) (1)	Example of calculation $\tan\theta = \frac{0.50\text{ m}}{1.45\text{ m}} \therefore \theta = 19.0°$ $\tan\theta = \frac{0.40\text{ m}}{1.45\text{ m}} \therefore \theta = 15.4°$ $d = \frac{650 \times 10^{-9}\text{ m}}{\sin 19.0°} = 1.99 \times 10^{-6}$ m $\lambda_2 = 1.99 \times 10^{-6}$m $\times \sin 15.4° = 5.29 \times 10^{-7}$m	5

Q5.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• use of $n\lambda = d\sin\theta$ (1) • use of $1/d$ (1) • 520 000 lines per metre (1)	Example calculation $d = 650 \times 10^{-9}$ m / sin 19.9° $= 1.9 \times 10^{-6}$ m $1/ 1.9 \times 10^{-6}$ m = 520 000 lines per metre	**(3)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)	• measure angle for first order on either side and divide by 2 (1) • if there is a zero error it will be eliminated (1) OR • measure a larger angle (1) • this will reduce the percentage uncertainty (1)		**(2)**

Q6.

Question Number	Answer	Mark
	D – using laser light with a higher frequency	**1**
	Incorrect Answers: A – this would have no effect B – this would make the maxima further from the central maximum C – this would make the maxima further from the central maximum	

Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• laser light should not be aimed directly into the eye (1) • as concentrated beam can cause damage to the retina (1)		**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	EITHER • all x values should be recorded to the same number of decimal places, so x_2 and x_4 are incorrectly recorded (1) OR • all processed data should be recorded to the same number of significant figures, so sin θ for x_1 is incorrectly recorded	Do not award repeat readings, not appropriate in this experiment	**(1)**
(b)(ii)	• use of $\tan\theta = \frac{x}{D}$ [θ = 22.9°] (1) • $\sin\theta$ = 0.390 (1)	Example of calculation: $\tan\theta = \frac{0.741}{1.75} = 0.423$ $\therefore \theta = 22.9°$ $\therefore \sin\theta = 0.3899$	**(2)**
(b)(iii)	point plotted correctly and best straight line drawn through points (1)		**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(iv)	• $\sin\theta = \frac{n\lambda}{d}$, so gradient = $\frac{\lambda}{d}$ (1) • gradient = 0.194 (1) • use of d = 1/number of lines per mm (1) • d = 3.33×10^{-6} (m) (1) • λ = 6.5×10^{-7} m (1)	Example of calculation: $d = \frac{1}{3\times10^{5}\,\text{m}^{-1}} = 3.33\times10^{-6}\,\text{m}$ $\lambda = 3.33\times10^{-6}\,\text{m}\times0.194$ $= 6.47\times10^{-7}\,\text{m}$	**(5)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)	An answer that makes reference to two of the following pairs: • use a Vernier scale to record *x* (1) • so that data to the nearest 0.1 cm could be obtained to reduce the percentage uncertainty (1) • use a larger grating to screen distance (1) • so that all *x* values would be greater to reduce the percentage uncertainty (1) • measure from nth order on one side to nth order on the other side (1) • so that the distance measured is larger hence reducing the percentage uncertainty in x (1) • use a grating with more lines per mm (1) • so that values of *x* will be greater to reduce the percentage uncertainty (1)	Do not award repeat readings, not appropriate in this experiment	**(4)**

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
	• measure distance from grating to screen *l* and from centre to dot *x* **(1)** • use $\tan\theta = x / l$ to determine θ **(1)**		**2**

Question Number	Acceptable answers		Additional guidance	Mark
	• Axes with labels • scales • plots • line of best fit	(1) (1) (1) (1)	**MP2**: scales only in 1,2,4,5 and must cover at least half of paper **MP3**: a 2 mm square tolerance, check all points	4

Question Number	Acceptable answers		Additional guidance	Mark
	• calculation of a gradient • use gradient = d/λ • use d = 0.001 / 300 • wavelength = 6.3×10^{-7} m	(1) (1) (1) (1)	Example of calculation $\text{gradient} = \frac{4.0}{0.76} = 5.26$ $\frac{0.001}{300} = 5.26 \times \lambda$ wavelength = 6.3×10^{-7} m	4

Q9.

Question Number	Acceptable answers		Additional guidance	Mark
	• calculation of a gradient • use gradient = d/λ • use d = 0.001 / 300 • wavelength = 6.3×10^{-7} m	(1) (1) (1) (1)	Example of calculation $\text{gradient} = \frac{4.0}{0.76} = 5.26$ $\frac{0.001}{300} = 5.26 \times \lambda$ wavelength = 6.3×10^{-7} m	4

Q10.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• set up diffraction grating at right angles to light from laser (1) **Or** set up grating parallel to screen • measure the distance between the diffraction grating and the screen (1) • measure the distance between 1st order images on the screen (1)	An annotated diagram could score these marks MP3 accept between other correct specified orders.	3

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• use of $d\sin\theta = n\lambda$ (1) • Calculation of one of the diffraction angles (for any n) (1) • Attempt to calculate a difference in the angles (1) **Or** statement that the two angles are very similar • So (accurate) measurement would be very difficult (1) **Or** the difference in wavelength could not be determined with this grating	MP4 dependent on MP3 Example of calculation: $\sin\theta_1 = \frac{656.2\times10^{-9}\,\text{m}}{2.2\times10^{-6}\,\text{m}}$ $\therefore \theta_1 = 17.354°$ $\sin\theta_2 = \frac{656.0\times10^{-9}\,\text{m}}{2.2\times10^{-6}\,\text{m}}$ $\therefore \theta_1 = 17.348°$ $\therefore \Delta\theta = 17.354° - 17.348° = 0.006°$	4

Q11.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	An explanation that makes reference to: • waves/light passing through a narrow gap spread/s out **(1)** • light reaches the wall from each part of the slit with differing phase relationships **(1) OR** light reaches the wall from each part of the slit with differing path lengths **(1)** • when the waves meet superposition takes place and if the waves are in antiphase it results in destructive interference so a dark spot is seen **(1) OR** when the waves meet superposition takes place and if the waves are in phase it results in constructive interference so a bright(er) region is seen **(1)**	Accept relevant reference to Huygen's construction for first mark.	**3**
(b)	An explanation that makes reference to: • green light has a shorter wavelength than red light **(1)** **OR** red light has a longer wavelength that green light **(1)** • so green light diffracts less than red light **or** red light diffracts more than green light **(1)** • so the dark points would be closer to the centre or more dark points would be seen in the same space on the wall or central fringe narrower **(1)**	Accept a diagram clearly to the same scale and showing a narrowed pattern. MP2 and MP3 may be awarded if reference is made to frequency difference rather than wavelength.	**3**
(c)	• use of trigonometrical functions to calculate θ **(1)** • calculate diffraction grating spacing **(1)** • wavelength = 5.1×10^{-7} m **(1)**	Example of calculation: $\theta = \tan^{-1}(0.23\text{ m}/1.5\text{ m}) = 8.7°$ $d = 10^{-3}/300 = 3.3 \times 10^{-6}$ m $\lambda = 3.3 \times 10^{-6}$ m $\times \sin 8.7°$ $= 5.1 \times 10^{-7}$ m	**3**

Q12.

Question Number	Acceptable Answers	Additional guidance	Mark
(i)	Any one • Monochromatic **or** small range of wavelength / frequencies • Coherent • Little divergence of wave over a distance • Produces plane wavefronts		**1**
(ii)	• $d = 0.005$ mm **or** use of $d = \frac{1}{200\text{ mm}^{-1}}$ **(1)** **(1)** • Use of tan to find θ **(1)** • Use of $n\lambda = d\sin\theta$ with $n = 3$ **(1)** • $\lambda = 5.4 \times 10^{-7}$ (m) • Concludes that the laser light is green **Or** conclusion consistent with their value of λ **(1)**	Example of Calculation $d = \frac{1}{200\text{ mm}^{-1}} = 0.005$ mm $\theta = \tan^{-1}\left(\frac{1.02\text{ m}}{3.0\text{ m}}\right) = 18.8°$ $\lambda = \frac{(5\times10^{-6}\text{m})\times\sin 18.8°}{3} = 5.37 \times 10^{-7}$m so light is green	**5**

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• The electrons/atoms can only exist in discrete/specific energy levels (in the sodium atoms) (1) • Electrons/atoms become excited **Or** Electrons/atoms move to higher energy levels (1) • The electrons/atoms then move to lower energy levels, giving out energy in the form of photons (1) • The energy of the photon is equal to the energy difference between the energy levels (1) • $E = hf$ and $\lambda = c/f$ so wavelength depends on the photon energy (1) • There are only certain energy transitions possible (between discrete levels) so only certain frequencies/wavelengths are visible. (1)	accept $E = hc / \lambda$ MP6 – Allow reference to few or limited number for 'certain'. Allow reference to discrete differences in energy levels.	6

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(ii)	• Use of $n\lambda = d \sin\theta$ **(1)** • $d = 1.77 \times 10^{-6}$ m **(1)** • Choose $d = 2.0 \times 10^{-6}$ m as a smaller value than $d = 1.77 \times 10^{-6}$ m would cause greater diffraction angles so the third order would not be seen, but 3.3×10^{-6} m would produce smaller angles than 2.0×10^{-6} m, causing larger relative uncertainty in measurement **(1)** **(1)** **Or** • Use of $n\lambda = d \sin\theta$ • A correct value of sin θ or θ $d = 1.0 \times 10^{-6}$ m → 1.77 $d = 1.7 \times 10^{-6}$ m → 1.04 $d = 2.0 \times 10^{-6}$ m → 0.88 62.° $d = 3.3 \times 10^{-6}$ m → 0.535 32.° **(1)** • Choose $d = 2.0 \times 10^{-6}$ m. 1.7×10^{-6} m would give a sine value greater than 1, so no 3rd order is visible, and 3.3×10^{-6} m would produce smaller angles than 2.0×10^{-6} m, causing larger relative uncertainty in measurement **(1)**	Example of calculation $3 \times 5.89 \times 10^{-7}$ m = $d \sin 90°$ $d = 1.77 \times 10^{-6}$ m	**3**

Q14.

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>*</td><td>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.

<table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5 - 4</td><td>3</td></tr><tr><td>3 - 2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table></td><td>The following table shows how the marks should be awarded for structure and lines of reasoning

<table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table></td><td></td></tr>
<tr><td></td><td>Indicative content

• This is a diffraction/interference pattern

• Electrons behave as waves

• As speed/momentum increases the circles get smaller

• n$\lambda = d\sin\theta$ used to justify that as θ decreases λ decreases

• Refers de Broglie equation ($\lambda = h/p$) to confirm that as speed/momentum increases, wavelength decreases.

• Crystal has a regular/layered structure</td><td>PP2 Do not credit 'electrons behave as waves or particles' on its own
PP3 accept circles get condensed for circles get smaller

PP4 do not credit use of equation to justify λ same size as gaps in crystal or to measure the gaps in the graphite

PP6 small gaps at uniform distances/lengths Or accept that graphite is made up of more than a single crystal</td><td>6</td></tr>
</table>

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Q15.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is **C** because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, and there are that many orders either side of the maximum plus a central order A is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, and there are that many orders either side of the maximum plus a central order, but this answer only gives the number of orders on one side of the central order B is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, but this order rounds 4.7 to 5 and doesn't consider the central maximum or that there are orders on either side D is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, but this order rounds 4.7 to 5 and then adds the orders on the other side and the central maximum		1