PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 5: WAVES AND PARTICLE NATURE OF LIGHT

PARTICLE NATURE OF LIGHT AND THE WAVE-PARTICLE DUALITY

SCORE	PERCENTAGE
/925	%

STEMUP

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Mark Scheme

Q1.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• The deflection/fields experiments indicate that electrons have a mass (and a charge) **Or** the deflection/fields experiments indicate that electrons have particle behaviour. **(1)** • The diffraction experiments indicate that electrons must have a wave nature **(1)** • Idea that a model of electron behaviour must include wave-particle duality **(1)**	In MP1 allow a description of deflection e.g. electrons are deflected by (electric and magnetic) fields indicating that they have a mass (and charge)	3

Q2.

Question Number	Answer	Mark
	B	1

Q3.

Question Number	Answer	Mark
	B – decreasing the speed of the electrons in the beam	1
	Incorrect Answers: A – the number of electrons does not affect the angle C - the number of electrons does not affect the angle D – increasing the speed would decrease the distance between the rings	

Q4.

Question Number	Answer	Mark
	A	1

Q5.

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• 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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Q6.

Question Number	Answer	Mark
	D their wave nature	**1**
	Incorrect Answers: **A** not demonstrated by this observation **B** not demonstrated by this observation **C** not demonstrated by this observation	

Mark Scheme

Q1.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Conversion of MeV to J (1) • See $Q_1 = 79 \times 1.6 \times 10^{-19}$ and $Q_2 = 2 \times 1.6 \times 10^{-19}$ (1) • Use of $V = \frac{Q}{4\pi\varepsilon_0 r}$ and $W = QV$ (1) • $r = 4.1\times10^{-14}$ m (1)	Example of calculation $E_\alpha = 5.5\times10^{6}\text{eV}\times1.6\times10^{-19}\text{J eV}^{-1} = 8.8\times10^{-13}\text{J}$ $8.8\times10^{-13}\text{J} = \frac{79\times1.6\times10^{-19}\text{C}\times2\times1.6\times10^{-19}\text{C}}{4\pi\times8.85\times10^{-12}\text{ F m}^{-1}\ r}$ $r = \frac{3.64\times10^{-26}\text{ N m}^2}{8.8\times10^{-13}\text{ J}} = 4.1\times10^{-14}\text{ m}$	4
(ii)	• Electrons are behaving like waves (1) • wavelength $= \frac{h}{\text{momentum}}$ (1) • Electron wavelength must be similar to the atomic spacing in the foil (1)	MP3: Accept electron wavelength must be similar to the distance between (adjacent) nuclei	3

Q2.

Question Number	Acceptable Answers	Additional guidance	Mark
(i)	• Use of $\lambda = \frac{h}{p}$ (1) • recognise $\lambda = 2 \times$ diameter of atom (1) • 1.7×10^{-24} kg m s^{-1} (1)	Example of calculation $p = \frac{6.63 \times 10^{-34}\ (\text{J s})}{2\times 2.0\times 10^{-10}\ (\text{m})} = 1.67\times 10^{-24}$ kg m s^{-1}	3
(ii)	• A discrete number of half wavelengths fit into the diameter of an atom (1) • Reference to $E = \frac{hc}{\lambda}$ to link wavelength to discrete energy levels (1)		2

Q3.

Question Number	Acceptable Answers	Additional guidance	Mark
	• Use of $p = mv$ using mass of electron (1) • Use of $\lambda = \frac{h}{p}$ (1) • $\lambda = 3.3 \times 10^{-11}$ m (1)	Example of Calculation $\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{9.11 \times 10^{-31}\text{kg} \times 2.2 \times 10^{7}\ \text{m s}^{-1}}$ $\lambda = 3.3 \times 10^{-11}$ m	3

Q4.

Question Number	Answer	Mark
	B	1

Q5.

Question Number	Answer	Additional Guidance	Mark
	• Use of $\lambda = \frac{h}{p}$ **Either** • $h = 6.7 \times 10^{-34}$ (J s) • compares answer to 6.63×10^{-34} (J s) **Or** • $\lambda = 1.38 \times 10^{-10}$ (m) • compares answer to 1.40×10^{-10} (m)	<u>Example of calculation</u> $h = 1.4 \times 10^{-10}$ m $\times 4.8 \times 10^{-24}$ kg m s^{-1} $h = 6.7 \times 10^{-34}$ J s $\approx 6.63 \times 10^{-34}$ J s	**3**

Q6.

Question Number	Answer	Mark
	B	**1**

Q7.

Question Number	Answer	Mark
	C	**1**

Q8.

Question Number	Answer		Mark
(a) (i)	Use of $\lambda = h/p$ and $p = mv$ **Or** $v = h/m\lambda$ Use of $m = 9.11 \times 10^{-31}$ kg $v = 7.28 \times 10^{6}$ m s^{-1} Example of calculation $\lambda = h/mv$ $v = 6.63 \times 10^{-34}$ J s /(9.11×10^{-31} kg $\times$ 1.0×10^{-10} m) $v = 7.28 \times 10^{6}$ m s^{-1}	(1) (1) (1)	3
(a) (ii)	Use of $E_k = ½ mv^2$ **Or** $E_k = p^2/2m$ **Or** see $E_k = 2.41 \times 10^{-17}$ J Divided by 1.60×10^{-19} $E_k = 151$ eV (accept values in range 150 – 152 eV) (ecf value of v from (a)) Example of calculation $E_k = ½ (9.11 \times 10^{-31}$ kg$)(7.28 \times 10^{6}$ m s$^{-1})^2 / (1.60 \times 10^{-19}$ J eV$^{-1})$ $E_k = 151$ eV	(1) (1) (1)	3
(b)	The wavelength is similar in size to the nucleus The wavelength /nucleus is (much) smaller / 10^{-15}m / 10^{-14} m (if value is not given, 'wavelength is small' or 'wavelength is very small' is not sufficient)	(1) (1)	2

Q9.

Question Number	Answer		Mark
(a)	The wavelength (associated) with a particle/electron with a given momentum **Or** $\lambda = h/p$ all terms defined	(1) (1) (1) (1)	2
(b)(i)	Use of $E_k = eV$ Use of $E_k = p^2/2m$ **Or** use of $E_k = mv^2/2$ **and** $p = mv$ Momentum $= 1.21 \times 10^{-23}$ kg m s^{-1} Example of calculation $E_k = 1.6 \times 10^{-19}$ C$\times$ 500 V $p^2 = 2 m E_k = 2 \times 9.11 \times 10^{-31}$ kg $\times$ $(1.6 \times 10^{-19} \times 500)$ J $p = 1.21 \times 10^{-23}$ kg m s^{-1}	(1) (1) (1)	3
(b)(ii)	Use of $\lambda = h/p$ $\lambda = 5.49 \times 10^{-11}$ m (ecf value of p from (i)) (show that value gives 6.63×10^{-11} m) Example of calculation $p = 6.63 \times 10^{-34}$ J s / 1.21×10^{-23} kg m s^{-1} $\lambda = 5.49 \times 10^{-11}$ m	(1) (1)	2
	Total for question		7

Q10.

Question Number	Answer	Mark
	C	**1**

Q11.

Question Number	Answer	Mark
	B – decreasing the speed of the electrons in the beam	1
	Incorrect Answers: A – the number of electrons does not affect the angle C - the number of electrons does not affect the angle D – increasing the speed would decrease the distance between the rings	

Q12.

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 **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 (1) • path difference at X is $\lambda/2$ **Or** path difference at Y is λ (1) • (electron) waves at X are in antiphase **Or** (electron) waves at Y are in phase (1) • at X destructive interference/superposition takes place **Or** at Y constructive interference/superposition takes place (1)	MP1 accept use of $p = mv$ **and** Use of $E_k = ½ mv^2$ MP4 accept (n + ½) λ or n λ respectively Example of calculation $p = \sqrt{(2 \times 9.11 \times 10^{-31}\text{ kg} \times 9.6 \times 10^{-17}\text{ J})}$ $p = 1.32 \times 10^{-23}$ 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

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
	C		1

Q14.

Question Number	Answer	Mark
	C $\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times v}$	1
	Incorrect Answers: **A** Incorrect value for h **B** Incorrect arrangement and incorrect value for h **D** Incorrect arrangement	

Q15.

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IC3 and IC4 must include a mention of the walls/container
</td>
<td>6</td>
</tr>
</table>

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	Indicative content: 1. As the temperature of the gas increases the (average) speed/E_k of the atoms increases 2. Greater speed/E_k so the momentum of the atoms increases 3. The rate/frequency of collision of atoms with the container walls increases **Or** the time between collisions with the walls decreases 4. The rate of change of momentum at the walls increases 5. Rate of change of momentum is equal to the force 6. Pressure is $\frac{\text{force}}{\text{area}}$ and the force (on the walls) is greater		

Q16.

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• 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>
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Q17.

Question Number	Acceptable answers	Additional guidance	Mark
(a)(i)	• Use of $\lambda = h/p$ and $v = f\lambda$ (1) • Momentum of photon = 3.3×10^{-27} (N s) (1)	Example of calculation Momentum of photon = $p = hf/c$ $= 6.63 \times 10^{-34}$ J s $\times 1.5 \times 10^{15}$ Hz $\div 3.00 \times 10^{8}$ m s^{-1} $= 3.315 \times 10^{-27}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(a)(ii)	• Momentum transfer = 6.6×10^{-27} (N s) (1)	Ecf momentum from (i) in parts (a)(ii) and (c)	1

Question Number	Acceptable answers	Additional guidance	Mark
(b)(i)	• Use of $hf = \varphi + \frac{1}{2} mv^2_{max}$ (1) • Use of $E_K = \frac{1}{2} mv^2$ (1) • $v = 8.4 \times 10^5$ (m s^{-1}) (1)	Example of calculation $hf = \varphi + \frac{1}{2} mv^2_{max}$ $hf = 6.63 \times 10^{-34}$ J s $\times 1.5 \times 10^{15}$ Hz $= 9.95 \times 10^{-19}$ J $hf - \varphi = 9.95 \times 10^{-19}$ J $- 6.7 \times 10^{-19}$ J $= 3.25 \times 10^{-19}$ J 3.25×10^{-19} J $= \frac{1}{2} \times 9.11 \times 10^{-31}$ kg $\times v^2$ $v = 8.4 \times 10^5$ m s^{-1}	3

Question Number	Acceptable answers	Additional guidance	Mark
(b)(ii)	• Use of $p = mv$ (1) • Momentum of photoelectron = 7.7×10^{-25} N s (1)	Example of calculation $p = 9.11 \times 10^{-31}$ kg $\times 8.4 \times 10^5$ m s^{-1} Momentum of photoelectron = 7.68×10^{-25} N s MP2: Using show that value $p = 7.3 \times 10^{-25}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(c)	An explanation that refers to the following points: • the change in momentum of the graphene oxide is the same as the change in momentum of the photoelectron (1) • so the (change in) momentum is much larger for the photoelectron than for the reflected photon (1)	Accept converse statement and answer that is consistent with candidate's values in (a) and (b)	2

Q18.

Question Number	Acceptable Answers	Additional guidance	Mark
	• Use of $p = mv$ with m= 9.11×10^{-31} and $v = 0.02 \times 3.0 \times 10^{8}$ (1) • Use of $\lambda = \frac{h}{p}$ (1) • $\lambda = 1.2 \times 10^{-10}$ m (1)	Example of calculation $\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{9.11 \times 10^{-31}\ \text{kg} \times 0.02 \times 3.0 \times 10^{8}\ \text{m s}^{-1}}$ $\lambda = 1.2 \times 10^{-10}$ m	3

Q19.

Question Number	Answer	Mark
	C kg m^2 s^{-1}	**1**
	Incorrect Answers: **A** – N is not an SI base unit and incorrect arrangement **B** – N is not an SI base unit **D** – incorrect arrangement	

Mark Scheme

Q1.

Question Number	Answer		Mark
(a)	photon absorbed by electron electron moves to higher energy level **Or** electron excited where photon energy = difference in energy levels only certain changes/differences possible between discrete energy levels	(1) (1) (1) (1) (1)	5
(b)(i)	Use of $E = hf$ Use of conversion factor to eV Energy of photon = 1.91 (eV) Identify levels 3.41 (eV) and 1.51 (eV) **Or** levels 1 and 2 Example of calculation $E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz (= 3.05×10^{-19} J) $E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz $\div$ 1.6×10^{-19} J s = 1.91 eV = 3.41 eV − 1.51 eV (1.90 eV) as the closest match	(1) (1) (1) (1)	4
(b)(ii)	Just-free electrons have zero energy state **Or** energy value of level $n = \infty$ is 0 (Bound) electrons need to gain energy to attain this state **Or** electrons need to gain energy to move to a higher level (Accept Because they must gain energy to move up for second mark) (accept answers in terms of ionisation energy)	(1) (1)	2
(c)	Look for corresponding pattern of lines / frequency spacings at different place in spectrum **Or** reference to known normal positions moving away increases observed wavelength / decreases frequency (or the case for moving towards) so if shifted to red end then moving away (or blue = towards) **Or** the greater the velocity the greater the change in frequency	(1) (1) (1)	3
	Total for question		14

Q2.

Question Number	Answer		Mark
(a)*	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Electrons/atoms move to higher energy levels / get excited They then move to lower energy levels (accept ground state) The energy from the move is given out in the form of a <u>photon</u> The energy levels are discrete **Or** only certain energy levels are possible The energy of the photon must be equal to the difference in energy levels **Or** $hf = E_2 - E_1$ There are only a limited number of energy differences and only a corresponding number of frequencies (looking for differences /changes **not** levels) (The marks above may be obtained from a suitably labelled diagram – but the order of excitation and de-excitation cannot be assumed for two marks just from the presence of both)	(1) (1) (1) (1) (1) (1)	6
(b)	Doppler (accept blue shift) The wavelength of the radiation is decreased / frequencies increases Star moving towards Earth or vice versa	(1) (1) (1)	3
(c)	Light behaves as both particle and wave **Or** wave-particle duality	(1)	1
	Total for question		10

Q3.

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Indicative content

photon energy $E = hf$
photon energy must be greater than work function (of metal) for photon to provide enough energy for photoemission
UV photons have sufficient energy for photoemission but lab light photons do not
one photon interacts with one electron
with larger area more photons are absorbed/incident in a given time
more electrons are emitted in a given time (so the charge is lost more quickly)

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IC2 accept answers in terms of threshold frequency
IC5 & 6 there must be the idea of 'rate' once
<table>
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<tr><td>0,1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6</td><td>2</td></tr>
</table>
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<td>6</td>
</tr>
</table>

Q4.

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

Q5.

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

Q6.

Question Number	Answer	Additional Guidance	Mark
	• Experimental evidence became available (eg speed of light in water) **or** wave model could be used to explain other properties of light **or** Huygens' construction could be used to explain interference/diffraction (1) • further support for wave theory by other scientists (eg Thomas Young) **or** (younger) scientists were willing to accept new ideas (1)	MP1 the idea of evidence MP2 the idea of further support	**2**

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	Acceptable Answers	Additional Guidance	Mark
	• Light is an electromagnetic wave **Or** Light is oscillations of electric and magnetic fields (1) • Oscillations are perpendicular to the direction of energy transfer (1)	Accept direction of wave travel	**2**

Q9.

Question Number	Answer	Mark
	D visible line spectra	**1**
	Incorrect Answers: **A** – wave model **B** – wave model **C** – wave model	

Q10.

Question Number	Answer		Mark
(a)	max kinetic energy **Or** ke_{max}	(1)	
	joule/J **Or** electronvolt/eV	(1)	
	Or	(1)	
	stopping potential **Or** V_s volt/V	(1)	**2**
	(Unit mark can be scored if no quantity given. If incorrect quantity given no marks awarded but KE/energy in joules/eV scores MP2)		
(b)	Idea that one photon is absorbed by one electron	(1)	
	Photon energy given by $E = hf$ **Or** photon energy increases with frequency	(1)	
	The idea that there is a minimum energy needed for emission of a (photo)electron	(1)	
	(So) emission of electrons only occurs if frequency of light greater than the threshold frequency **Or** threshold frequency is the minimum frequency for the emission of (photo)electrons	(1)	**4**
	Total for question		**6**

Q11.

Question Number	Acceptable answer	Additional guidance	Mark
	D	The only correct answer is **D**: a wave of greater intensity would still transfer energy at a greater rate which could release photoelectrons at a greater rate even if they could absorb energy continuously A is not correct because time would be required for absorption of sufficient wave energy B is not correct because absorption of sufficient wave energy would occur over time C is not correct because at higher intensities the waves would have higher amplitudes and energy could increase over time to higher values	1

Q12.

Question Number	Answer	Mark
	The only correct answer is C because wave nature would predict a greater emission rate with a greater incident power A because instantaneous emission is only predicted by particle nature B because dependence of maximum kinetic energy on frequency is only predicted by particle nature D because minimum frequency for emission is only predicted by particle nature	1

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
*	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.	The following table shows how the marks should be awarded for structure and lines of reasoning	

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

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	Indicative content Observations • Photoelectrons emitted instantaneously when radiation incident on surface • There is no photoemission below the threshold frequency • The maximum ke of the photoelectrons is independent of the intensity of the incident radiation • The rate of photoemission is proportional to the intensity of the incident radiation Models • One photon is absorbed by one electron **Or** all of the energy of one photon is transferred to one electron • With waves, energy can be supplied to the electron continuously **Or** with waves, energy can 'build up'	There are 4 observations and 2 models. Linkage is demonstrated by linking observations and models. Two linkage marks can only be awarded if reference is made to both models and more than one observation	**6**

Q14.

Question Number	Answer		Mark
(a)	Quantum of … **Or** (discrete) packet of … **Or** discrete quantity of …	**(1)**	
	(To score the mark must refer to something relevant e.g. light / energy) Of <u>electromagnetic</u> radiation/energy	**(1)**	**2**
*** (b)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)	**(1)**	
	describe relevant interaction between single photon and single electron		
	photon energy depends on frequency **Or** reference to $E = hf$ (must be link to photons/light)	**(1)**	
	if photon energy greater than work function, electron emitted (immediately)	**(1)**	
	whereas for waves energy could build up **Or** with waves that the electron can absorb energy continuously or over time	**(1)**	**5**
	so any frequency should work **Or** but this build up doesn't happen		
(c)(i)	Use of $4.3 \times 1.6 \times 10^{-19}$	**(1)**	
	Use of $E = hf$	**(1)**	
	$f = 1.0 \times 10^{15}$ Hz	**(1)**	**3**
	<u>Example of calculation</u> $E = 4.3\ \text{V} \times 1.6 \times 10^{-19}\ \text{C}$ $= 6.9 \times 10^{-19}\ \text{J}$ $6.9 \times 10^{-19}\ \text{J} = 6.63 \times 10^{-34}\ \text{Js} \times f$ $f = 1.0 \times 10^{15}$ Hz		
(c)(ii)	Ultraviolet Accept ultraviolet even if frequency in c(i) is incorrect, but allow ecf from candidate's value of frequency to appropriate part of electromagnetic spectrum	**(1)**	**1**
	Total for question		**11**

Q15.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	An explanation that makes reference to: • quantisation of energy is the idea that energy is emitted/radiated in discrete packets/photons **(1)** • each photon has an energy which is related to frequency OR suitable reference to $E = hf$ **(1)**		**2**
(ii)	• Model A is successful at long wavelengths because the curve for model A follows the experimental curve **(1)** • But model A breaks down for short wavelengths, since it suggests that the intensity tends to infinity as the wavelength gets shorter **(1)** • Model B is successful for short wavelengths because curve B follows the experimental curve **(1)** • But model B indicates higher than expected intensities at larger wavelengths **(1)**		**4**

Q16.

Question Number	Acceptable Answers	Additional guidance	Mark
(i)	• Do not stare into laser (1)		**1**
(ii)	• Lack of other evidence (supporting wave theory) **Or** Was yet to be reproduced **Or** (1) There was support / evidence for the particle model		**1**

Q17.

<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 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.
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<tr><td>Number of indicative points seen in answer</td><td>Number of marks awarded for indicative points</td></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>
Particle model

One photon interacts with one electron
And each photon has energy proportional to the frequency, Or reference to $E=hf$
The electron is emitted (instantly) only if the energy of the photon is greater than the work function (of the metal)
Or The electron is emitted (instantly) only if the energy of the photon is greater than the energy needed for an electron to break free (from metal surface)
Any photon energy over and above the work function is gained by the electron as kinetic energy

Wave model

It would be expected that the energy of the electron would build up and eventually be emitted.
The (kinetic) energy of the (emitted) electrons would depend on the intensity of the wave (and not the frequency)

</td>
<td>The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><td></td><td>Number of marks awarded for structure and lines of reasoning</td></tr>
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</table>
Linkage marks
<table>
<tr><th>Indicative content points</th><th>Possible linkage marks</th></tr>
<tr><td>0, 1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6 with points from both models</td><td>2</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

Q18.

Question Number	Answer		Mark
(a)	Diode / LED (Any type of recognised diode scores the mark but if diode is included in a list of other components the mark cannot be gained.)	(1)	1
(b)	Infinite / infinity / ∞ **Or** Very high **Or** very large	(1)	1
(c)	Use of $R=V/I$ Correct value of R for their current in range 0.40 A to 0.43 A (Any valid pair of values for first mark. Use of tangent or gradient scores no marks) Example of calculation R= 0.70 V / 0.41 A R= 1.7 Ω	(1) (1)	2
(d)	**Any One from, e.g.** To protect components / circuits Rectification Restricts current / flow (of charge) to one direction AC to DC Produce DC supply Power indicator light Light source, e.g. Christmas tree light, torch Regulate voltage (Accept any reasonable practical use for diode or LED)	(1)	1

Q19.

Question Number	Acceptable answers		Additional guidance	Mark
	• Wave model	(1)		
	Any two • (Demonstration) provided experimental evidence (in support of wave model)	(1)		
	• (Demonstration) supported previous evidence	(1)		
	• (This demonstration was) reproducible **Or** (This demonstration) could be repeated by others	(1)		3

Q20.

Question Number	Answer	Mark
	B	1

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	• Line of best fit drawn (1) • Gradient determined (1) • Applies eV to J conversion factor (1) • $h = 6.62 \times 10^{-34}$ J s (6.4×10^{-34} J s to 6.8×10^{-34} J s) (1) MP4 dependent on calculation from graph	Example of calculation Gradient = 4.14×10^{-15} $h = 4.14 \times 10^{-15}$ eV s $\times 1.6 \times 10^{-19}$ J eV^{-1} $h = 6.62 \times 10^{-34}$ J s	4

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	• x-intercept determined (1) • Use of $\phi = hf_0$ (1) • $\phi = 2.3$ eV, so metal is (probably) caesium (allow ecf for h from (a)) (1) **OR** • Reads a pair of co-ordinates from graph • Use of $\phi = hf - E$ • $\phi = 2.3$ eV, so metal is (probably) caesium (allow ecf for h from (a))	MP2: allow use of standard value for h or value of h determined in (a) <u>Example of calculation</u> $f_0 = 55 \times 10^{13}$ Hz $\phi = 6.62\times10^{-34}$ J s $\times 55\times10^{13}$ Hz $=3.64\times10^{-19}$ J $\phi = \frac{3.64 \times 10^{-19}\text{J}}{1.6 \times 10^{-19}\text{ J eV}^{-1}} = 2.28$ eV	3

Q3.

Question Number	Answer		Mark
(a)	photon absorbed by electron electron moves to higher energy level **Or** electron excited where photon energy = difference in energy levels only certain changes/differences possible between discrete energy levels	(1) (1) (1) (1) (1)	5
(b)(i)	Use of $E = hf$ Use of conversion factor to eV Energy of photon = 1.91 (eV) Identify levels 3.41 (eV) and 1.51 (eV) **Or** levels 1 and 2 Example of calculation $E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz (= 3.05×10^{-19} J) $E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz $\div$ 1.6×10^{-19} J s = 1.91 eV = 3.41 eV − 1.51 eV (1.90 eV) as the closest match	(1) (1) (1) (1)	4
(b)(ii)	Just-free electrons have zero energy state **Or** energy value of level $n = \infty$ is 0 (Bound) electrons need to gain energy to attain this state **Or** electrons need to gain energy to move to a higher level (Accept Because they must gain energy to move up for second mark) (accept answers in terms of ionisation energy)	(1) (1)	2
(c)	Look for corresponding pattern of lines / frequency spacings at different place in spectrum **Or** reference to known normal positions moving away increases observed wavelength / decreases frequency (or the case for moving towards) so if shifted to red end then moving away (or blue = towards) **Or** the greater the velocity the greater the change in frequency	(1) (1) (1)	3
	Total for question		**14**

Q4.

Question Number	Answer	Additional Guidance	Mark
	Use of $E = hf$ **and** $v = f\lambda$ (1) Conversion eV to J (1) $\lambda = 2.9 \times 10^{-7}$ m (1)	Example of calculation $\lambda = \frac{6.63\times10^{-34}\text{J s} \times 3.0\times10^{8}\text{m s}^{-1}}{4.3\text{ eV}\times 1.6\times10^{-19}\text{ C}} = 289$ nm	3

Q5.

<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 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.
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<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>
Indicative content

photon energy $E = hf$
photon energy must be greater than work function (of metal) for photon to provide enough energy for photoemission
UV photons have sufficient energy for photoemission but lab light photons do not
one photon interacts with one electron
with larger area more photons are absorbed/incident in a given time
more electrons are emitted in a given time (so the charge is lost more quickly)

</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 and lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
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<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
IC2 accept answers in terms of threshold frequency
IC5 & 6 there must be the idea of 'rate' once
<table>
<tr><th>Number of IC points awarded</th><th>Possible linkage marks</th></tr>
<tr><td>0,1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6</td><td>2</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	the lowest frequency (of incident radiation) that will cause the emission of (photo)electrons (from the surface)		**(1)**

Question Number	Acceptable answers		Additional guidance	Mark
(b)	• use of ½ $m v_{max}^2$	(1)	Example of calculation: $E = 6.63 \times 10^{-34}$ J s × 8.9 × 10^{14} Hz = 5.9×10^{-19} J ½ $m v_{max}^2$ = ½ × 9.11 × 10^{-31} kg × (6.7 × 10^5 m s^{-1})^2 = 2.045×10^{-19} J $\varphi = 5.9 \times 10^{-19}$ J – 2.045 × 10^{-19} J = 3.8×10^{-19} J = 1.8 × 10^{-19} J ÷ 1.6 × 10^{-19} C = 2.4 eV	**(4)**
	• use of $\varphi = hf$ – max ke	(1)		
	• divides energy in joule by 1.6 × 10^{-19} C	(1)		
	• φ = 2.4 eV	(1)		

Q7.

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

Q8.

Question Number	Answer	Mark
	D	**1**
	Incorrect Answers: A – absorption of the longest wavelength B – emission with the longest wavelength C – absorption of the shortest wavelength	

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $E = hf$ and $c = f\lambda$ **(1)** • Convert J to eV **(1)** • 2.1 eV **(1)** • Arrow drawn on diagram from −3.04 eV to −5.14 eV **(1)**	Example of calculation $E = 6.63 \times 10^{-34}$ Js $\times$ 3.00×10^{8} m s^{-1} / 5.89×10^{-7} m $= 3.38 \times 10^{-19}$ J 3.38×10^{-19} J / 1.60×10^{-19} C = 2.11 eV	**4**

Q10.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• use of difference in energy levels in eV and use of $W = QV$ for conversion to Joule **(1)** • use of $E = hf$ **(1)** • frequency = 7.2×10^{13} Hz **(1)**	Example of calculation: difference in energy levels = –0.55 eV – (–0.85 eV) = 0.3 eV = 0.3 V $\times$ 1.6×10^{-19} C = 4.8×10^{-20} J f = 4.8×10^{-20} J ÷ 6.63×10^{-34} Js = 7.2×10^{13} Hz	**3**

Q11.

Question Number	Answer		Mark
	electron emitted by absorption of light/UV/photon	(1)	
	one photon absorbed by one electron	(1)	
	if frequency above threshold frequency then electron emitted **Or** if photon energy above work function energy then electron emitted	(1)	
	Use of $hf = \varphi$ (using work function to find corresponding frequency or wavelength) **Or** Use photon energy = hf (using any identified frequency or wavelength of visible light or UV to find corresponding photon energy)	(1)	
	Threshold frequency = 1.0×10^{15} Hz **Or** wavelength = 2.9×10^{-7} m **Or** Photon energy for light = a value between 2.9×10^{-19} J and 5.1×10^{-19} J **Or** photon energy for UV = a value between 5.1×10^{-19} J and 1.99×10^{-17} J	(1)	
	State visible light frequency too low / wavelength too long **Or** compare photon energy to work function	(1)	6
	Example of calculation $f = 6.88 \times 10^{-19}$ J ÷ 6.33×10^{-34} J s $= 1.0 \times 10^{15}$ Hz		
	Total for question		6

Q12.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	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: Number of indicative marking points seen in answer / Number of marks awarded for indicative marking points 6 / 4 5 - 4 / 3 3 - 2 / 2 1 / 1 0 / 0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure	

The following table shows how the marks should be awarded for structure and lines of reasoning:

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Indicative content

- photon energy discrete/quantised

and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

- one photon transfers all of its energy to one electron
  Or one photon cause the emission of one (photo)electron
- photon must have energy greater than / equal to work function energy to release (photo)electron
- reference to $E = hf$
- if light was a wave, energy could build up
- if light was a wave, any frequency could provide sufficient energy in time there would be a current for all frequencies

(6)

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

(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 $\sin\theta$ 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.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• As graphene is only 1 atom thick so the CSA/thickness is far smaller than for a sample of steel **Or** most applications need a thickness greater than one atom **Or** if more than one layer of graphene is used it will be weaker or the bonds between the layers will not be strong **Or** Graphene is difficult to manufacture because it has only one atomic layer (1) • Although graphene has a greater breaking stress it will break at a lower force (1)	MP1: accept graphene can only be 1 atom thick but steel can be any thickness (MP1, treat references to cost/energy as neutral)	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)	• Use of depth of graphite = 100 × diameter of 1 carbon atom (1) • Use of cross-sectional area = depth × (0.5×10^{-3} m) (1) • Use of $\rho = \frac{RA}{l}$ (1) • $\rho = 3.6 \times 10^{-5}\ \Omega$ m **Or** 36 μΩ m	Example of calculation Depth of graphite = $100 \times 1.4 \times 10^{-10}$ m = 1.4×10^{-8} m CSA = 1.4×10^{-8} m × 0.50×10^{-3} m = 7.0×10^{-12} m^2 $\rho = \frac{1.029 \times 10^{6}\Omega \times 7.0 \times 10^{-12}\text{m}^2}{0.200\text{ m}} =$ $3.6 \times 10^{-5}\ \Omega$ m	4

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)	**Max 3** • Silicon will only release a (photo) electron for a limited range of frequencies/wavelengths (1) • Silicon releases only one (photo) electron per incident photon (1) • Greater current (for the same illumination) in graphene (1) • Graphene (cells are) more efficient **Or** graphene cells could be smaller / cheaper / thinner	MP1: accept single frequency for limited range	3

Q15.

Question number	Acceptable answers	Additional guidance	Mark
(i)	**Either** • When x = R_0, F = GMm/R_0^2 **(1)** • F = $GMmR_0/R_0^3$ so k = $m\omega^2 = GMm/R_0^3$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • From graph F=-(g/R_o)r **(1)** • From which $\omega = \sqrt{(g/R_0)}$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • So $T = 2\pi\sqrt{(R_o^3/g)}$ **(1)**		**4**

Question number	Acceptable answers	Additional guidance	Mark
(ii)	**Either** Centripetal force = $mv^2/R_0 = GMm/R_0^2$ **(1)** • $4\pi^2 R_0^2/ T^2R_0 = GM/R_0^2$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • $mg = mv^2/R_0 = m\,\omega^2R_0$ **(1)** • So $\omega = \sqrt{(g/R_0)}$ **(1)** • $T = 2\pi/\omega = 2\pi\sqrt{(R_0/g)}$ **(1)**		**3**

Q16.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Light consists of (particles called) photons **(1)** • These particles: are discrete packets of energy **Or** are quanta of energy **(1)** **Or** have momentum		**2**

Q17.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)(i)	• a π^0 may be $u\bar{u}$ **Or** $d\bar{d}$ (1) • it must be a quark combined with its own antiquark so that overall charge is 0 (1) OR it can only contain up or down quarks (as it is not a strange particle)	Allow $s\bar{s}$	**(2)**
(a)(ii)	mesons are made up of quarks, whereas leptons are fundamental particles (1)		**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	• use of v = s/t (1) • t = 5.05 × 10^{-5} s (1)	Example of calculation: $t = \frac{s}{v} = \frac{15\times10^{3}\,\text{m}}{0.99\times3\times10^{8}\,\text{ms}^{-1}} = 5.05\times10^{-5}\text{s}$	**(2)**
(b)(ii)	• use of $\lambda t_{1/2} = 0.693$ (1) • λ = 3.15 × 10^{5} s^{-1} (1) • use of $N = N_0 e^{-\lambda t}$ (1) • $\frac{N}{N_0} = 1.23\times10^{-7}$ (1)	Example of calculation: $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{2.2\times10^{-6}\text{s}} = 3.15\times10^{5}\text{s}^{-1}$ $\frac{N}{N_0} = e^{-\lambda t} = e^{-3.15\times10^{5}\text{s}^{-1}\times5.05\times10^{-5}\text{s}} = 1.23\times10^{-7}$ $\frac{N}{N_0} = 1.1\times10^{-7}$ if "show that" value used	**(4)**
(b)(iii)	• This is much smaller than 10% indicating the muon lifetime is much greater than the expected value (1) • The high speed of the muon has led to relativistic effects (1)		**(2)**

Q18.

Question Number	Answer		Mark
(a)	max kinetic energy **Or** ke_{max}	(1)	
	joule/J **Or** electronvolt/eV	(1)	
	Or	(1)	
	stopping potential **Or** V_s volt/V	(1)	2
	(Unit mark can be scored if no quantity given. If incorrect quantity given no marks awarded but KE/energy in joules/eV scores MP2)		
(b)	Idea that one photon is absorbed by one electron	(1)	
	Photon energy given by $E = hf$ **Or** photon energy increases with frequency	(1)	
	The idea that there is a minimum energy needed for emission of a (photo)electron	(1)	
	(So) emission of electrons only occurs if frequency of light greater than the threshold frequency **Or** threshold frequency is the minimum frequency for the emission of (photo)electrons	(1)	4
	Total for question		6

Q19.

Question Number	Acceptable Answer		Additional Guidance	Mark
	The student's answer should			
	• Include the idea that 'threshold' refers to a (minimum) frequency	(1)	For MP1, accept that wavelength has to be below a certain 'threshold'	
	• state that photons have an energy given by hf	(1)		
	• recognise that the energy used to release electrons is called the work function	(1)	**Max 3** if the response is not a discussion of the student's answer	4
	• include the idea that one photon is absorbed by one electron	(1)		

Q20.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• work function = hf_0	(1)	Example of calculation	
	• use of $hf = \varphi + ½ mv^2_{max}$	(1)	work function = hf_0	
	• division by 1.6×10^{-19}	(1)	$= 6.63 \times 10^{-34}$ J s $\times$ 8.17 $\times 10^{14}$ Hz	
	• $V = 0.60$ V	(1)	$= 5.42 \times 10^{-20}$ J	
			½ mv^2_{max} $= (6.63 \times 10^{-34}$ J s $\times$ 9.62 $\times 10^{14}$ Hz) – 5.42 $\times 10^{-20}$ J	
			$= 9.61 \times 10^{-20}$ J	
			$V = 9.61 \times 10^{-20}$ J / 1.6 $\times 10^{-19}$ C	
			$V = 0.60$ V	**(4)**

Q21.

Question Number	Acceptable answers		Additional guidance	Mark
	• Substitute eV for ½ mv^2_{max} in $hf = \phi +$ ½ mv^2_{max}	(1)	Example of calculation	4
	• Rearranges to identify gradient = h/e	(1)	$hf = \phi + ½ mv^2_{max}$	
		(1)	$hf = \phi + eV$	
	• Attempt to find gradient using large triangle	(1)	$eV = hf - \phi$	
			$V = hf/e - \phi/e$	
	• $h = 7.6 \times 10^{-34}$ J s		gradient = h/e	
	(range: 7.5×10^{-34} J s to 7.7×10^{-34} J s)		gradient = (2.40 V – 1.00 V) ÷ (6.975×10^{14} Hz – 4.025×10^{14} Hz)	
			gradient = 4.72×10^{-34} V s	
			$h = 4.72 \times 10^{-34}$ V s $\times 1.6 \times 10^{-19}$ C	
			$h = 7.58 \times 10^{-34}$ J s	

Q22.

Question Number	Acceptable answers	Additional guidance	Mark
(a)(i)	• Use of $\lambda = h/p$ and $v = f\lambda$ (1) • Momentum of photon = 3.3×10^{-27} (N s) (1)	Example of calculation Momentum of photon = $p = hf/c$ $= 6.63 \times 10^{-34}$ J s $\times 1.5 \times 10^{15}$ Hz $\div 3.00 \times 10^{8}$ m s^{-1} $= 3.315 \times 10^{-27}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(a)(ii)	• Momentum transfer = 6.6×10^{-27} (N s) (1)	Ecf momentum from (i) in parts (a)(ii) and (c)	1

Question Number	Acceptable answers	Additional guidance	Mark
(b)(i)	• Use of $hf = \varphi + ½ mv^2_{max}$ (1) • Use of $E_K = ½ mv^2$ (1) • $v = 8.4 \times 10^5$ (m s^{-1}) (1)	Example of calculation $hf = \varphi + ½ mv^2_{max}$ $hf = 6.63 \times 10^{-34}$ J s $\times 1.5 \times 10^{15}$ Hz $= 9.95 \times 10^{-19}$ J $hf - \varphi = 9.95 \times 10^{-19}$ J $- 6.7 \times 10^{-19}$ J $= 3.25 \times 10^{-19}$ J 3.25×10^{-19} J $= ½ \times 9.11 \times 10^{-31}$ kg $\times v^2$ $v = 8.4 \times 10^5$ m s^{-1}	3

Question Number	Acceptable answers	Additional guidance	Mark
(b)(ii)	• Use of $p = mv$ (1) • Momentum of photoelectron = 7.7×10^{-25} N s (1)	Example of calculation $p = 9.11 \times 10^{-31}$ kg $\times 8.4 \times 10^5$ m s^{-1} Momentum of photoelectron = 7.68×10^{-25} N s MP2: Using show that value $p = 7.3 \times 10^{-25}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(c)	An explanation that refers to the following points: • the change in momentum of the graphene oxide is the same as the change in momentum of the photoelectron (1) • so the (change in) momentum is much larger for the photoelectron than for the reflected photon (1)	Accept converse statement and answer that is consistent with candidate's values in (a) and (b)	2

Q23.

Question Number	Acceptable answers	Additional guidance	Mark
	• (Faint and difficult to see, so may not be seen at the correct p.d. and) recorded p.d. could be too high **(1)** • (Range of frequencies could mean light is seen before the light at the stated frequency and) recorded p.d. could be too low **(1)** • Discussion of these points, e.g. opposite effects, could cancel or could be systematic errors and not affect gradient **(1)**		3

Q24.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• Use of $E = \frac{1}{2}mv^2$ (1) • Use of $E = hf$ **and** $c = f\lambda$ (1) • $\lambda = (2.4 - 2.5) \times 10^{-7}$(m) (1) • leading to a conclusion that radiation is ultraviolet **Or** conclusion consistent with their value for wavelength (1)	MP4 dependent on MP2 Example of Calculation $\Delta E_k = \frac{1}{2} \times 9.11 \times 10^{-31}\,\text{kg} \times ((2.5 \times 10^6\,\text{m s}^{-1})^2 - (2.1 \times 10^6\,\text{m s}^{-1})^2)$ $\Delta E_k = 8.4 \times 10^{-19}$ (J) $\lambda = \frac{6.63 \times 10^{-34}\,\text{J s} \times 3 \times 10^8\,\text{m s}^{-1}}{8.4 \times 10^{-19}\,\text{J}}$ $\lambda = 2.4 \times 10^{-7}$(m)	4

Q25.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	An explanation that makes reference to: • quantisation of energy is the idea that energy is emitted/radiated in discrete packets/photons **(1)** • each photon has an energy which is related to frequency OR suitable reference to $E = hf$ **(1)**		**2**
(ii)	• Model A is successful at long wavelengths because the curve for model A follows the experimental curve **(1)** • But model A breaks down for short wavelengths, since it suggests that the intensity tends to infinity as the wavelength gets shorter **(1)** • Model B is successful for short wavelengths because curve B follows the experimental curve **(1)** • But model B indicates higher than expected intensities at larger wavelengths **(1)**		**4**

Mark Scheme

Q1.

Question Number	Acceptable Answers	Additional guidance	Mark
	• (High intensity of light means) photons strike the photocell at a greater rate (1) • One to one interaction between photons and electrons (1) • So Electrons released at a greater rate (1) • So greater current/charge/power in external circuit (1)		4

Q2.

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. 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 Indicative content • photon energy $E = hf$ • photon energy must be greater than work function (of metal) for photon to provide enough energy for photoemission • UV photons have sufficient energy for photoemission but lab light photons do not • one photon interacts with one electron • with larger area more photons are absorbed/incident in a given time • more electrons are emitted in a given time (so the charge is lost more quickly)	The following table shows how the marks should be awarded for structure and lines of reasoning Number of marks awarded for structure and lines of reasoning Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout / 2 Answer is partially structured with some linkages and lines of reasoning / 1 Answer has no linkage between points and is unstructured / 0 IC2 accept answers in terms of threshold frequency IC5 & 6 there must be the idea of 'rate' once **Number of IC points awarded** / **Possible linkage marks** 0,1 / 0 2, 3 / 1 4, 5, 6 / 2	6

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Q3.

Question Number	Answer	Mark
(a)	Lowest / minimum frequency (of light / photons incident on a metal) that will cause electrons to be emitted (from surface) **Or** the frequency of (light / photons) that will cause electrons to be emitted (from the surface of a metal) with zero kinetic energy **(1)** (accept only just emitted)	1
(b)	Conversion of eV to J **(1)** Use of $E = hf$ **(1)** $f = 5.5 \times 10^{14}$ Hz **(1)** Example of calculation $\varphi = (2.28 \text{ eV} \times 1.6 \times 10^{-19} \text{ C})$ $= 3.65 \times 10^{-19}$ J $f = 3.65 \times 10^{-19} \text{ J} / 6.63 \times 10^{-34} \text{ J s} = 5.50 \times 10^{14}$ Hz	3
	Total for Question	**4**

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	the lowest frequency (of incident radiation) that will cause the emission of (photo)electrons (from the surface)		**(1)**

Question Number	Acceptable answers		Additional guidance	Mark
(b)	• use of $½ m v_{max}^2$	(1)	Example of calculation: $E = 6.63 \times 10^{-34}$ J s × 8.9 × 10^{14} Hz = 5.9×10^{-19} J	**(4)**
	• use of $\varphi = hf$ – max ke	(1)	$½ m v_{max}^2 = ½ \times 9.11 \times 10^{-31}$ kg × $(6.7 \times 10^5 \text{ m s}^{-1})^2 = 2.045 \times 10^{-19}$ J $\varphi = 5.9 \times 10^{-19} \text{ J} - 2.045 \times 10^{-19} \text{ J} = 3.8 \times 10^{-19}$ J	
	• divides energy in joule by 1.6×10^{-19} C	(1)	$= 1.8 \times 10^{-19} \text{ J} \div 1.6 \times 10^{-19}$ C	
	• φ = 2.4 eV	(1)	= 2.4 eV	

Q5.

Question Number	Answer		Mark
	electron emitted by absorption of light/UV/photon	(1)	
	one photon absorbed by one electron	(1)	
	if frequency above threshold frequency then electron emitted **Or** if photon energy above work function energy then electron emitted	(1)	
	Use of $hf = \varphi$ (using work function to find corresponding frequency or wavelength) **Or** Use photon energy = hf (using any identified frequency or wavelength of visible light or UV to find corresponding photon energy)	(1)	
	Threshold frequency = 1.0×10^{15} Hz **Or** wavelength = 2.9×10^{-7} m **Or** Photon energy for light = a value between 2.9×10^{-19} J and 5.1×10^{-19} J **Or** photon energy for UV = a value between 5.1×10^{-19} J and 1.99×10^{-17} J	(1)	
	State visible light frequency too low / wavelength too long **Or** compare photon energy to work function	(1)	6
	Example of calculation $f = 6.88 \times 10^{-19}$ J ÷ 6.33×10^{-34} J s $= 1.0 \times 10^{15}$ Hz		
	Total for question		**6**

Q6.

Question number	Acceptable answers	Additional guidance	Mark
(i)	• use of $F = Q_1Q_2/4\pi\varepsilon_0 r^2$ **(1)** • use of $F = Gm_1m_2/r^2$ **(1)** • Expresses forces as a ratio **(1)** **OR** calculates the individual forces F_e=8.1 x 10^{-8} N F_g = • 3.6 x 10^{-47} N **(1)** • Ratio = 2 x 10^{39} or 5 x 10^{-40} and identifies gravitational force as insignificant **(1)**		**4**
(ii)	• use of $F = mv^2/r$ and $F = Q_1Q_2/4\pi\varepsilon_0 r^2$ **(1)** • to derive $v = \sqrt{\frac{Q_1Q_2}{4\pi\epsilon_0 rm}}$ **(1)** • velocity = 2.2× 10^6 m s^{-1} **(1)**	Example of calculation: $v = \sqrt{\frac{Q_1Q_2}{4\pi\epsilon_0 rm}}$ $v = \sqrt{\frac{1.6\times10^{-19}\text{ C}\times1.6\times10^{-19}\text{ C}}{4\pi\times8.85^{-12}\text{ Fm}^{-1}\times5.3\times10^{-11}\text{m}\times9.1\times10^{-81}\text{ kg}}}$ $v = 2.185 \times 10^6$ m s^{-1}	**3**

Q7.

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>(i)</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>

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>

Indicative content
• photon energy discrete/quantised</td><td>Guidance on how the mark scheme should be applied:

The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).</td><td></td></tr>
</table>

	• one photon transfers all of its energy to one electron **Or** one photon cause the emission of one (photo)electron • photon must have energy greater than / equal to work function energy to release (photo)electron • reference to $E = hf$ • if light was a wave, energy could build up • if light was a wave, any frequency could provide sufficient energy in time there would be a current for all frequencies		**(6)**

Q8.

Question Number	Answer		Mark
(a)	Oscillations/vibrations (of molecules) parallel to direction of propagation **Or** oscillations parallel to direction of wave travel **Or** oscillations parallel to direction of energy transfer Produces compressions and rarefactions	**(1)** **(1)**	**2**
(b)	Otherwise there wouldn't be a way of telling which bit of reflected sound originated with which bit of emitted sound **Or** so one returns before one emitted	 **(1)**	**1**
(ci)	time (= 1÷16 Hz) = 0.063 (s) (at least 2 sf)	**(1)**	**1**
(cii)	Use of factor of 2 Use of $v = s/t$ distance = 48 m (Use of 'show that' value gives 46m) <u>Example of calculation</u> 2 × distance = 1530 m s^{-1} × 0.063 s distance = 48 m	**(1)** **(1)** **(1)**	**3**
(ciii)	A shorter time between clicks because the distance is shorter **Or** more frequent clicks allow rapid motion to be perceived. **Or** allow position to be determined precisely/accurately.	 **(1)**	**1**
(d)	Speed in air lower than speed in water So wavelength in air shorter than wavelength in water **Or** pulse length in air is shorter than pulse length in water **Or** attempt at numerical comparison of wavelength or pulse length So bat echolocation will detect smaller targets **Or** detect smaller differences in position (conditional on MP2) (Accept 'show more detail' or 'better resolution')	**(1)** **(1)** **(1)**	**3**
	Total for question		**11**

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Q9.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• As graphene is only 1 atom thick so the CSA/thickness is far smaller than for a sample of steel **Or** most applications need a thickness greater than one atom **Or** if more than one layer of graphene is used it will be weaker or the bonds between the layers will not be strong **Or** Graphene is difficult to manufacture because it has only one atomic layer (1) • Although graphene has a greater breaking stress it will break at a lower force (1)	MP1: accept graphene can only be 1 atom thick but steel can be any thickness (MP1, treat references to cost/energy as neutral)	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)	• Use of depth of graphite = 100 × diameter of 1 carbon atom (1) • Use of cross-sectional area = depth × (0.5×10^{-3} m) (1) • Use of $\rho = \frac{RA}{l}$ (1) • $\rho = 3.6 \times 10^{-5}\ \Omega$ m **Or** 36 μΩ m	Example of calculation Depth of graphite = $100 \times 1.4 \times 10^{-10}$ m = 1.4×10^{-8} m CSA = 1.4×10^{-8} m × 0.50×10^{-3} m = 7.0×10^{-12} m^2 $\rho = \frac{1.029 \times 10^{6}\Omega \times 7.0 \times 10^{-12}\text{m}^2}{0.200\text{ m}} =$ $3.6 \times 10^{-5}\ \Omega$ m	4

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)	**Max 3** • Silicon will only release a (photo) electron for a limited range of frequencies/wavelengths (1) • Silicon releases only one (photo) electron per incident photon (1) • Greater current (for the same illumination) in graphene (1) • Graphene (cells are) more efficient **Or** graphene cells could be smaller / cheaper / thinner	MP1: accept single frequency for limited range	3

Q10.

Question Number	Answer	Additional Guidance	Mark
	• one photon interacts with one electron (1) • when the energy of the photon is equal to or greater than the work function (of the metal) an electron is released (1) • energy of photon = hf so there is a minimum/threshold frequency (1)		3

Q11.

Question Number	Acceptable answer	Additional guidance	Mark
	D	The only correct answer is **D**: a wave of greater intensity would still transfer energy at a greater rate which could release photoelectrons at a greater rate even if they could absorb energy continuously A is not correct because time would be required for absorption of sufficient wave energy B is not correct because absorption of sufficient wave energy would occur over time C is not correct because at higher intensities the waves would have higher amplitudes and energy could increase over time to higher values	1

Q12.

Question Number	Acceptable Answer	Additional Guidance	Mark
	The student's answer should • Include the idea that 'threshold' refers to a (minimum) frequency (1) • state that photons have an energy given by hf (1) • recognise that the energy used to release electrons is called the work function (1) • include the idea that one photon is absorbed by one electron (1)	For MP1, accept that wavelength has to be below a certain 'threshold' **Max 3** if the response is not a discussion of the student's answer	4

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Q13.

Question Number	Answer		Mark
(a)	max kinetic energy **Or** ke_{max}	(1)	
	joule/J **Or** electronvolt/eV	(1)	
	Or	(1)	
	stopping potential **Or** V_s volt/V	(1)	2
	(Unit mark can be scored if no quantity given. If incorrect quantity given no marks awarded but KE/energy in joules/eV scores MP2)		
(b)	Idea that one photon is absorbed by one electron	(1)	
	Photon energy given by $E = hf$ **Or** photon energy increases with frequency	(1)	
	The idea that there is a minimum energy needed for emission of a (photo)electron	(1)	
	(So) emission of electrons only occurs if frequency of light greater than the threshold frequency **Or** threshold frequency is the minimum frequency for the emission of (photo)electrons	(1)	4
	Total for question		6

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><th>Max linkage mark available</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
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</table>
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</table>
Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).
</td><td></td></tr>
</table>

<table>
<tr><td></td><td>
Indicative content

Observations

Photoelectrons emitted instantaneously when radiation incident on surface
There is no photoemission below the threshold frequency
The maximum ke of the photoelectrons is independent of the intensity of the incident radiation
The rate of photoemission is proportional to the intensity of the incident radiation

Models

One photon is absorbed by one electron
Or all of the energy of one photon is transferred to one electron
With waves, energy can be supplied to the electron continuously
Or with waves, energy can 'build up'

</td><td>
There are 4 observations and 2 models. Linkage is demonstrated by linking observations and models.

Two linkage marks can only be awarded if reference is made to both models and more than one observation
</td><td>6</td></tr>
</table>

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Q15.

Question Number	Acceptable Answers		Additional guidance	Mark
	Max 6 **Similarities** • An electron absorbs a photon **Or** electrons gain energy from a photon	(1)		6
	• photons need a minimum amount of energy	(1)		
	• So light must be above a certain frequency	(1)		
	• increasing the light intensity increases the number of electrons (released per sec)	(1)		
	• Evidence for the particle model of light	(1)		
	Differences • In the photoelectric effect electrons are released from the surface	(1)		
	• But electrons remain within the LDR	(1)		
	• Photoelectric effect occurs in metals **Or** LDR is a semiconductor	(1)		

Q16.

Question Number	Answer		Mark
(a)	**When illuminated:** Use of the word photon photons/light cause emission of (photo)electrons Idea that (photo) electrons form a current photon energy greater than or equal to work function. **In darkness:** No photons so no photoelectrons released	(1) (1) (1) (1) (1)	5
(b)	Use of $E = hf$ Conversion of eV to J One of the 4 values below correct $f = 5.2 \times 10^{14}$ Hz or $\lambda = 5.8 \times 10^{-7}$ m for caesium $f = 8.8 \times 10^{14}$ Hz or $\lambda = 3.4 \times 10^{-7}$ m for zinc Comment that Cs is in the visible range or Zn is ultraviolet – allow even without supporting calculation **Alternative method** Allow assumed max freq/min wavelength for visible light then, calculation of work function, quoted in eV, comparison with given work functions, conclusion: Use of (1); work fn (1), in eV (1), comparison (1) Example of calculation $f = \varphi \div h = (2.14 \times 1.6 \times 10^{-19})$ J $\div 6.63 \times 10^{-34}$ J s $= 5.2 \times 10^{14}$ Hz for caesium $f = \varphi \div h = (3.63 \times 1.6 \times 10^{-19})$ J $\div 6.63 \times 10^{-34}$ J s $= 8.8 \times 10^{14}$ Hz for zinc	(1) (1) (1) (1)	4
(ci)	Maximum displacement of the wave **Or** maximum displacement from the mean **Or** maximum displacement from equilibrium	(1)	1
(cii)	**Max 3** Size of the gap (in the soundtrack) determines the amount of light Amount of light determines number of photons Number of photons determines number of (photo) electrons (released by phototube) Number of electrons determines size of current (in the circuit) (Combining MP 1 and 2 by writing "size of the gap determines number of photons" scores 1 mark. Combining MP 2 and 3 by writing "the amount of light determines number of (photo) electrons" also scores 1 mark)	(1) (1) (1) (1)	3
	Total for question		13

Q17.

Question Number	Acceptable answers	Additional guidance	Mark
(a)(i)	• Use of $\lambda = h/p$ and $v = f\lambda$ (1) • Momentum of photon = 3.3×10^{-27} (N s) (1)	Example of calculation Momentum of photon = $p = hf/c$ $= 6.63 \times 10^{-34}$ J s $\times 1.5 \times 10^{15}$ Hz $\div 3.00 \times 10^{8}$ m s^{-1} $= 3.315 \times 10^{-27}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(a)(ii)	• Momentum transfer = 6.6×10^{-27} (N s) (1)	Ecf momentum from (i) in parts (a)(ii) and (c)	1

Question Number	Acceptable answers	Additional guidance	Mark
(b)(i)	• Use of $hf = \varphi + ½ mv^2_{max}$ (1) • Use of $E_K = ½ mv^2$ (1) • $v = 8.4 \times 10^5$ (m s^{-1}) (1)	Example of calculation $hf = \varphi + ½ mv^2_{max}$ $hf = 6.63 \times 10^{-34}$ J s $\times 1.5 \times 10^{15}$ Hz $= 9.95 \times 10^{-19}$ J $hf - \varphi = 9.95 \times 10^{-19}$ J $- 6.7 \times 10^{-19}$ J $= 3.25 \times 10^{-19}$ J 3.25×10^{-19} J $= ½ \times 9.11 \times 10^{-31}$ kg $\times v^2$ $v = 8.4 \times 10^5$ m s^{-1}	3

Question Number	Acceptable answers	Additional guidance	Mark
(b)(ii)	• Use of $p = mv$ (1) • Momentum of photoelectron = 7.7×10^{-25} N s (1)	Example of calculation $p = 9.11 \times 10^{-31}$ kg $\times 8.4 \times 10^5$ m s^{-1} Momentum of photoelectron = 7.68×10^{-25} N s MP2: Using show that value $p = 7.3 \times 10^{-25}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(c)	An explanation that refers to the following points: • the change in momentum of the graphene oxide is the same as the change in momentum of the photoelectron (1) • so the (change in) momentum is much larger for the photoelectron than for the reflected photon (1)	Accept converse statement and answer that is consistent with candidate's values in (a) and (b)	2

Q18.

Question Number	Answer		Mark
(a)	Quantum of … **Or** (discrete) packet of … **Or** discrete quantity of …	**(1)**	
	(To score the mark must refer to something relevant e.g. light / energy) Of <u>electromagnetic</u> radiation/energy	**(1)**	**2**
*** (b)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)	**(1)**	
	describe relevant interaction between single photon and single electron		
	photon energy depends on frequency **Or** reference to $E = hf$ (must be link to photons/light)	**(1)**	
	if photon energy greater than work function, electron emitted (immediately)	**(1)**	
	whereas for waves energy could build up **Or** with waves that the electron can absorb energy continuously or over time	**(1)**	**5**
	so any frequency should work **Or** but this build up doesn't happen		
(c)(i)	Use of $4.3 \times 1.6 \times 10^{-19}$	**(1)**	
	Use of $E = hf$	**(1)**	
	$f = 1.0 \times 10^{15}$ Hz	**(1)**	**3**
	<u>Example of calculation</u> $E = 4.3\ \text{V} \times 1.6 \times 10^{-19}\ \text{C}$ $= 6.9 \times 10^{-19}\ \text{J}$ $6.9 \times 10^{-19}\ \text{J} = 6.63 \times 10^{-34}\ \text{Js} \times f$ $f = 1.0 \times 10^{15}$ Hz		
(c)(ii)	Ultraviolet Accept ultraviolet even if frequency in c(i) is incorrect, but allow ecf from candidate's value of frequency to appropriate part of electromagnetic spectrum	**(1)**	**1**
	Total for question		**11**

Q19.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• (UV radiation consists of) photons	**(1)**	Accept quanta/packets of energy	
	• One photon interacts with one electron **Or** energy of photon depends on frequency	**(1)**		
	• Electrons released if energy (of photon) greater than work function **Or** frequency is greater than threshold frequency **Or** <u>energy</u> supplied is sufficient to remove electron	**(1)**		**3**

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Question Number	Acceptable answers		Additional guidance	Mark
(b)(i)	• when slider at the bottom - reading on voltmeter is zero **Or** minimum resistance - reading on voltmeter is zero	(1)		3
	• When slider at the top – reading on voltmeter is 1.5 V **Or** maximum resistance - reading on voltmeter is 1.5 V	(1)		
	• Potential difference split between top and bottom part of resistor (either side of slider) **Or** reading on voltmeter depends on the ratio of resistances (either side of slider) **Or** moving the slider changes the resistance that the voltmeter is across	(1)		

Question Number	Acceptable answers		Additional guidance	Mark
(b)(ii)	Maximum Kinetic Energy of electron = 0.6 (eV)	(1)		1

Question Number	Acceptable answers		Additional guidance	Mark
(c)	**Max 4**		Full marks can only be scored if a correct link is made between at least one physics point and the demonstration being valid or not valid	4
	Valid because:			
	• Moon and photocell both have vacuum	(1)		
	• Both demonstration and theory use photoelectric effect	(1)	Accept the same concept for photoelectric effect	
	Not valid because:			
	• Different wavelengths in each case	(1)	Accept one uses light the other UV	
	• On the moon there is dust not metal	(1)	Accept different materials for MP4	
	• Dust is free to move but the metal plate is fixed	(1)		
	• On the moon UV removes electrons from (individual) <u>atoms</u> **and** in the demo light removes electrons from metal <u>surface</u>	(1)		
	• Demonstration is based on photoelectric effect but effect on moon could be ionisation	(1)		

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Q20.

<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 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.
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<tr><th>Number of indicative points seen in answer</th><th>Number of marks awarded for indicative points</th></tr>
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<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>
Particle model

One photon interacts with one electron
And each photon has energy proportional to the frequency, Or reference to $E=hf$
The electron is emitted (instantly) only if the energy of the photon is greater than the work function (of the metal)
Or The electron is emitted (instantly) only if the energy of the photon is greater than the energy needed for an electron to break free (from metal surface)
Any photon energy over and above the work function is gained by the electron as kinetic energy

Wave model

It would be expected that the energy of the electron would build up and eventually be emitted.
The (kinetic) energy of the (emitted) electrons would depend on the intensity of the wave (and not the frequency)

</td>
<td>The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
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<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
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<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
Linkage marks
<table>
<tr><th>Indicative content points</th><th>Possible linkage marks</th></tr>
<tr><td>0, 1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6 with points from both models</td><td>2</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

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Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of gradient (1) • h from graph = 6.74×10^{-34} J s (1) • Suitable percentage calculation allowing comparison with 1% and conclusion (1)	Example of calculation gradient = 3.00×10^{-19} J ÷ (10.15×10^{14} Hz – 5.70×10^{14} Hz) $h = 6.74 \times 10^{-34}$ J s percentage difference = (6.74×10^{-34} J s – 6.63×10^{-34} J s) /6.63×10^{-34} J s × 100% = 1.66% which is greater than 1% so it is not within 1% **Or** 6.63×10^{-34} J s × 101% = 6.70×10^{-34} J s which is smaller than 6.74×10^{-34} J s so it is not within 1%	3

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	• Line of best fit drawn (1) • Gradient determined (1) • Applies eV to J conversion factor (1) • $h = 6.62 \times 10^{-34}$ J s (6.4×10^{-34} J s to 6.8×10^{-34} J s) (1) MP4 dependent on calculation from graph	Example of calculation Gradient = 4.14×10^{-15} $h = 4.14 \times 10^{-15}$ eV s $\times 1.6 \times 10^{-19}$ J eV^{-1} $h = 6.62 \times 10^{-34}$ J s	4

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• x-intercept determined (1) • Use of $\phi = hf_0$ (1) • $\phi = 2.3$ eV, so metal is (probably) caesium (allow ecf for h from (a)) (1) **OR** • Reads a pair of co-ordinates from graph • Use of $\phi = hf - E$ • $\phi = 2.3$ eV, so metal is (probably) caesium (allow ecf for h from (a))	MP2: allow use of standard value for h or value of h determined in (a) <u>Example of calculation</u> $f_0 = 55 \times 10^{13}$ Hz $\phi = 6.62\times10^{-34}$ J s $\times 55\times10^{13}$ Hz $=3.64\times10^{-19}$ J $\phi = \frac{3.64 \times 10^{-19}\text{J}}{1.6 \times 10^{-19}\text{ J eV}^{-1}} = 2.28$ eV	3

Q4.

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td></td>
<td>
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<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
Indicative content

photon energy $E = hf$
photon energy must be greater than work function (of metal) for photon to provide enough energy for photoemission
UV photons have sufficient energy for photoemission but lab light photons do not
one photon interacts with one electron
with larger area more photons are absorbed/incident in a given time
more electrons are emitted in a given time (so the charge is lost more quickly)

</td>
<td>
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><td></td><td>Number of marks awarded for structure and lines of reasoning</td></tr>
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</table>
IC2 accept answers in terms of threshold frequency
IC5 & 6 there must be the idea of 'rate' once
<table>
<tr><th>Number of IC points awarded</th><th>Possible linkage marks</th></tr>
<tr><td>0,1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6</td><td>2</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

Q5.

Question Number	Answer	Mark
(a)	Lowest / minimum frequency (of light / photons incident on a metal) that will cause electrons to be emitted (from surface) **Or** the frequency of (light / photons) that will cause electrons to be emitted (from the surface of a metal) with zero kinetic energy (1) (accept only just emitted)	1
(b)	Conversion of eV to J (1) Use of $E = hf$ (1) $f = 5.5 \times 10^{14}$ Hz (1) Example of calculation $\varphi = (2.28 \text{ eV} \times 1.6 \times 10^{-19} \text{ C})$ $= 3.65 \times 10^{-19}$ J $f = 3.65 \times 10^{-19}$ J / 6.63×10^{-34} J s = 5.50×10^{14} Hz	3
	Total for Question	4

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	the lowest frequency (of incident radiation) that will cause the emission of (photo)electrons (from the surface)		**(1)**

Question Number	Acceptable answers		Additional guidance	Mark
(b)	• use of $\frac{1}{2} m v_{max}^2$	(1)	Example of calculation: $E = 6.63 \times 10^{-34}$ J s × 8.9×10^{14} Hz = 5.9×10^{-19} J $\frac{1}{2} m v_{max}^2 = \frac{1}{2} \times 9.11 \times 10^{-31}$ kg × $(6.7 \times 10^5$ m s$^{-1})^2 = 2.045 \times 10^{-19}$ J $\varphi = 5.9 \times 10^{-19}$ J − 2.045×10^{-19} J = 3.8×10^{-19} J = 1.8×10^{-19} J ÷ 1.6×10^{-19} C = 2.4 eV	**(4)**
	• use of $\varphi = hf$ − max ke	(1)		
	• divides energy in joule by 1.6×10^{-19} C	(1)		
	• φ = 2.4 eV	(1)		

Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Photoelectric equation stated in words **(1)** **Or** $hf = \phi + \frac{1}{2}mv_{max}^2$ with ϕ defined • Hence $eV_s = hf - \phi$ **(1)** **Or** $E_{k\,max} = hf - \phi$ **and** $E_{k\,max} = eV_s$ • Compare with $y = mx + c$ **(1)** • So plot a graph of V_s against f **(1)** **Or** plot a graph of eV_s against f • Gradient $= \frac{h}{e}$ **(1)** **Or** gradient $= h$	MP1: Accept hf_0 for ϕ [with f_0 defined], and $E_{k\,max}$ for $\frac{1}{2}mv_{max}^2$ MP2: eV_s does not have to be the subject of the equation MP5 is dependent upon MP4	5

Q8.

Question Number	Answer	Mark
	A – amount of energy of a photon needed to release an electron	1
	Incorrect Answers: B- an electron does not release a photon C – reference to frequency incorrect D - reference to frequency incorrect and electron does not release a photon	

Q9.

Question Number	Answer		Mark
	electron emitted by absorption of light/UV/photon	(1)	
	one photon absorbed by one electron	(1)	
	if frequency above threshold frequency then electron emitted **Or** if photon energy above work function energy then electron emitted	(1)	
	Use of $hf = \varphi$ (using work function to find corresponding frequency or wavelength) **Or** Use photon energy = hf (using any identified frequency or wavelength of visible light or UV to find corresponding photon energy)	(1)	
	Threshold frequency = 1.0×10^{15} Hz **Or** wavelength = 2.9×10^{-7} m **Or** Photon energy for light = a value between 2.9×10^{-19} J and 5.1×10^{-19} J **Or** photon energy for UV = a value between 5.1×10^{-19} J and 1.99×10^{-17} J	(1)	
	State visible light frequency too low / wavelength too long **Or** compare photon energy to work function	(1)	6
	Example of calculation $f = 6.88 \times 10^{-19}$ J ÷ 6.33×10^{-34} J s $= 1.0 \times 10^{15}$ Hz		
	Total for question		6

Q10.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	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: Number of indicative marking points seen in answer / Number of marks awarded for indicative marking points 6 / 4 5 - 4 / 3 3 - 2 / 2 1 / 1 0 / 0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure	

The following table shows how the marks should be awarded for structure and lines of reasoning:

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Indicative content

- photon energy discrete/quantised

and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

- one photon transfers all of its energy to one electron
  Or one photon cause the emission of one (photo)electron
- photon must have energy greater than / equal to work function energy to release (photo)electron
- reference to $E = hf$
- if light was a wave, energy could build up
- if light was a wave, any frequency could provide sufficient energy in time there would be a current for all frequencies

(6)

Q11.

Question Number	Answer	Mark
(a)	Oscillations/vibrations (of molecules) parallel to direction of propagation (1) **Or** oscillations parallel to direction of wave travel **Or** oscillations parallel to direction of energy transfer Produces compressions and rarefactions (1)	2
(b)	Otherwise there wouldn't be a way of telling which bit of reflected sound originated with which bit of emitted sound **Or** so one returns before one emitted (1)	1
(ci)	time (= 1÷16 Hz) = 0.063 (s) (at least 2 sf) (1)	1
(cii)	Use of factor of 2 (1) Use of $v = s/t$ (1) distance = 48 m (1) (Use of 'show that' value gives 46m) <u>Example of calculation</u> 2 × distance = 1530 m s^{-1} × 0.063 s distance = 48 m	3
(ciii)	A shorter time between clicks because the distance is shorter **Or** more frequent clicks allow rapid motion to be perceived. **Or** allow position to be determined precisely/accurately. (1)	1
(d)	Speed in air lower than speed in water (1) So wavelength in air shorter than wavelength in water **Or** pulse length in air is shorter than pulse length in water **Or** attempt at numerical comparison of wavelength or pulse length (1) So bat echolocation will detect smaller targets **Or** detect smaller differences in position (conditional on MP2) (1) (Accept 'show more detail' or 'better resolution')	3
	Total for question	11

Q12.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• As graphene is only 1 atom thick so the CSA/thickness is far smaller than for a sample of steel **Or** most applications need a thickness greater than one atom **Or** if more than one layer of graphene is used it will be weaker or the bonds between the layers will not be strong **Or** Graphene is difficult to manufacture because it has only one atomic layer (1) • Although graphene has a greater breaking stress it will break at a lower force (1)	MP1: accept graphene can only be 1 atom thick but steel can be any thickness (MP1, treat references to cost/energy as neutral)	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)	• Use of depth of graphite = 100 × diameter of 1 carbon atom (1) • Use of cross-sectional area = depth × (0.5×10^{-3} m) (1) • Use of $\rho = \frac{RA}{l}$ (1) • $\rho = 3.6 \times 10^{-5}\ \Omega$ m **Or** 36 μΩ m	Example of calculation Depth of graphite = $100 \times 1.4 \times 10^{-10}$ m = 1.4×10^{-8} m CSA = 1.4×10^{-8} m × 0.50×10^{-3} m = 7.0×10^{-12} m^2 $\rho = \frac{1.029 \times 10^{6}\Omega \times 7.0 \times 10^{-12}\text{m}^2}{0.200\text{ m}} =$ $3.6 \times 10^{-5}\ \Omega$ m	4

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)	**Max 3** • Silicon will only release a (photo) electron for a limited range of frequencies/wavelengths (1) • Silicon releases only one (photo) <u>electron</u> per incident photon (1) • Greater current (for the same illumination) in graphene (1) • Graphene (cells are) more efficient **Or** graphene cells could be smaller / cheaper / thinner	MP1: accept single frequency for limited range	3

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is **A** because, using Einstein's photoelectric equation, $hf = \varphi + \frac{1}{2} mv^2_{max}$, since the work function is constant, an increase in frequency results in an increase in the maximum kinetic energy of the photoelectrons B is not correct because, using Einstein's photoelectric equation, $hf = \varphi + \frac{1}{2} mv^2_{max}$, intensity has no effect on the maximum kinetic energy of the photoelectrons, just the rate at which they are emitted C is not correct because , using Einstein's photoelectric equation, $hf = \varphi + \frac{1}{2} mv^2_{max}$, and since the work function is equal to (the Planck constant × threshold frequency), a higher threshold frequency will lead to a lower maximum kinetic energy of the photoelectrons D is not correct because, using Einstein's photoelectric equation, $hf = \varphi + \frac{1}{2} mv^2_{max}$, a higher work function will lead to a lower maximum kinetic energy of the photoelectrons		1

Q14.

Question Number	Answer	Additional Guidance	Mark
	• one photon interacts with one electron (1) • when the energy of the photon is equal to or greater than the work function (of the metal) an electron is released (1) • energy of photon = hf so there is a minimum/threshold frequency (1)		3

Q15.

Question Number	Answer		Mark
(a)	max kinetic energy **Or** ke_{max}	(1)	
	joule/J **Or** electronvolt/eV	(1)	
	Or	(1)	
	stopping potential **Or** V_s volt/V	(1)	2
	(Unit mark can be scored if no quantity given. If incorrect quantity given no marks awarded but KE/energy in joules/eV scores MP2)		
(b)	Idea that one photon is absorbed by one electron	(1)	
	Photon energy given by $E = hf$ **Or** photon energy increases with frequency	(1)	
	The idea that there is a minimum energy needed for emission of a (photo)electron	(1)	
	(So) emission of electrons only occurs if frequency of light greater than the threshold frequency **Or** threshold frequency is the minimum frequency for the emission of (photo)electrons	(1)	4
	Total for question		6

Q16.

Question Number	Acceptable Answer		Additional Guidance	Mark
	The student's answer should			
	• Include the idea that 'threshold' refers to a (minimum) frequency	(1)	For MP1, accept that wavelength has to be below a certain 'threshold'	
	• state that photons have an energy given by hf	(1)		
	• recognise that the energy used to release electrons is called the work function	(1)	**Max 3** if the response is not a discussion of the student's answer	4
	• include the idea that one photon is absorbed by one electron	(1)		

Q17.

Question Number	Acceptable Answers	Additional Guidance	Mark
	C		1

Q18.

Question Number	Answer	Mark
	The only correct answer is C because wave nature would predict a greater emission rate with a greater incident power A because instantaneous emission is only predicted by particle nature B because dependence of maximum kinetic energy on frequency is only predicted by particle nature D because minimum frequency for emission is only predicted by particle nature	1

Q19.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• work function = hf_0	(1)	Example of calculation	
	• use of $hf = \varphi + ½\ mv^2_{max}$	(1)	work function = hf_0	
	• division by 1.6×10^{-19}	(1)	$= 6.63 \times 10^{-34}$ J s $\times$ 8.17 $\times 10^{14}$ Hz	
	• V = 0.60 V	(1)	$= 5.42 \times 10^{-20}$ J	
			$½\ mv^2_{max}$ $= (6.63 \times 10^{-34}$ J s $\times$ 9.62 $\times 10^{14}$ Hz) – 5.42 $\times 10^{-20}$ J	
			$= 9.61 \times 10^{-20}$ J	
			$V = 9.61 \times 10^{-20}$ J / 1.6 $\times 10^{-19}$ C	
			V = 0.60 V	(4)

Q20.

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<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
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</td>
<td></td>
</tr>
<tr>
<td></td>
<td>
Indicative content

Observations

• Photoelectrons emitted instantaneously when radiation incident on surface
• There is no photoemission below the threshold frequency
• The maximum ke of the photoelectrons is independent of the intensity of the incident radiation
• The rate of photoemission is proportional to the intensity of the incident radiation

Models
• One photon is absorbed by one electron
Or all of the energy of one photon is transferred to one electron
• With waves, energy can be supplied to the electron continuously
Or with waves, energy can 'build up'
</td>
<td>
There are 4 observations and 2 models. Linkage is demonstrated by linking observations and models.

Two linkage marks can only be awarded if reference is made to both models and more than one observation
</td>
<td>6</td>
</tr>
</table>

Q21.

Question Number	Answer	Mark
(a)	**When illuminated:** Use of the word photon (1) photons/light cause emission of (photo)electrons (1) Idea that (photo) electrons form a current (1) photon energy greater than or equal to work function. (1) **In darkness:** No photons so no photoelectrons released (1)	5
(b)	Use of $E = hf$ (1) Conversion of eV to J (1) One of the 4 values below correct $f = 5.2 \times 10^{14}$ Hz or $\lambda = 5.8 \times 10^{-7}$ m for caesium $f = 8.8 \times 10^{14}$ Hz or $\lambda = 3.4 \times 10^{-7}$ m for zinc (1) Comment that Cs is in the visible range or Zn is ultraviolet – allow even without supporting calculation (1) **Alternative method** Allow assumed max freq/min wavelength for visible light then, calculation of work function, quoted in eV, comparison with given work functions, conclusion: Use of (1); work fn (1), in eV (1), comparison (1) Example of calculation $f = \varphi \div h = (2.14 \times 1.6 \times 10^{-19})$ J $\div 6.63 \times 10^{-34}$ J s $= 5.2 \times 10^{14}$ Hz for caesium $f = \varphi \div h = (3.63 \times 1.6 \times 10^{-19})$ J $\div 6.63 \times 10^{-34}$ J s $= 8.8 \times 10^{14}$ Hz for zinc	4
(ci)	Maximum displacement of the wave **Or** maximum displacement from the mean **Or** maximum displacement from equilibrium (1)	1
(cii)	**Max 3** Size of the gap (in the soundtrack) determines the amount of light (1) Amount of light determines number of photons (1) Number of photons determines number of (photo) electrons (released by phototube) (1) Number of electrons determines size of current (in the circuit) (1) (Combining MP 1 and 2 by writing "size of the gap determines number of photons" scores 1 mark. Combining MP 2 and 3 by writing "the amount of light determines number of (photo) electrons" also scores 1 mark)	3
	Total for question	13

Q22.

Question Number	Acceptable answers	Additional guidance	Mark
(a)(i)	• Use of $\lambda = h/p$ and $v = f\lambda$ (1) • Momentum of photon = 3.3×10^{-27} (N s) (1)	Example of calculation Momentum of photon = $p = hf/c$ $= 6.63 \times 10^{-34}$ J s $\times 1.5 \times 10^{15}$ Hz $\div 3.00 \times 10^{8}$ m s^{-1} $= 3.315 \times 10^{-27}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(a)(ii)	• Momentum transfer = 6.6×10^{-27} (N s) (1)	Ecf momentum from (i) in parts (a)(ii) and (c)	1

Question Number	Acceptable answers	Additional guidance	Mark
(b)(i)	• Use of $hf = \varphi + ½ mv^2_{max}$ (1) • Use of $E_K = ½ mv^2$ (1) • $v = 8.4 \times 10^5$ (m s^{-1}) (1)	Example of calculation $hf = \varphi + ½ mv^2_{max}$ $hf = 6.63 \times 10^{-34}$ J s $\times 1.5 \times 10^{15}$ Hz $= 9.95 \times 10^{-19}$ J $hf - \varphi = 9.95 \times 10^{-19}$ J $- 6.7 \times 10^{-19}$ J $= 3.25 \times 10^{-19}$ J 3.25×10^{-19} J $= ½ \times 9.11 \times 10^{-31}$ kg $\times v^2$ $v = 8.4 \times 10^5$ m s^{-1}	3

Question Number	Acceptable answers	Additional guidance	Mark
(b)(ii)	• Use of $p = mv$ (1) • Momentum of photoelectron = 7.7×10^{-25} N s (1)	Example of calculation $p = 9.11 \times 10^{-31}$ kg $\times 8.4 \times 10^5$ m s^{-1} Momentum of photoelectron = 7.68×10^{-25} N s MP2: Using show that value $p = 7.3 \times 10^{-25}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(c)	An explanation that refers to the following points: • the change in momentum of the graphene oxide is the same as the change in momentum of the photoelectron (1) • so the (change in) momentum is much larger for the photoelectron than for the reflected photon (1)	Accept converse statement and answer that is consistent with candidate's values in (a) and (b)	2

Q23.

<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 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.
<table>
<tr><td>Number of indicative points seen in answer</td><td>Number of marks awarded for indicative points</td></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>
Particle model

One photon interacts with one electron
And each photon has energy proportional to the frequency, Or reference to $E=hf$
The electron is emitted (instantly) only if the energy of the photon is greater than the work function (of the metal)
Or The electron is emitted (instantly) only if the energy of the photon is greater than the energy needed for an electron to break free (from metal surface)
Any photon energy over and above the work function is gained by the electron as kinetic energy

Wave model

It would be expected that the energy of the electron would build up and eventually be emitted.
The (kinetic) energy of the (emitted) electrons would depend on the intensity of the wave (and not the frequency)

</td>
<td>The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><td></td><td>Number of marks awarded for structure and lines of reasoning</td></tr>
<tr><td>Answer shows a coherent and logical structure with linkage 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 linkage between points and is unstructured</td><td>0</td></tr>
</table>
Linkage marks
<table>
<tr><th>Indicative content points</th><th>Possible linkage marks</th></tr>
<tr><td>0, 1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6 with points from both models</td><td>2</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

Q24.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $c=f\lambda$ and $E=hf$ **(1)** • Converts eV to J **(1)** • Use of $E = W + KE_{max}$ **(1)** • $KE_{max} = 1.3 \times 10^{-19}$ J **(1)**	Example of calculation: $E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\text{J s}\times3\times10^{8}\text{m s}^{-1}}{2.54\times10^{-7}\text{m}} = 7.831\times10^{-19}\text{J}$ Work function = 6.51×10^{-19} J $E = W + KE_{\max}$ $KE_{\max} = 7.83\times10^{-19}\text{J} - 6.51\times10\text{ -}19\text{J} = 1.32\times10^{-19}\text{J}$	**4**

Q25.

Question Number	Acceptable Answers	Additional guidance	Mark
	• Use of $hf = \emptyset + \frac{1}{2}mv^2$ (1) • $v = 6.3 \times 10^{6}$ m s^{-1} (1)	Example of Calculation $E_k = (6.63\times10^{-34}\text{ J s}\times2.8\times10^{16}\text{ s}^{-1}) - 6.9\times10^{-19}\text{ (J)} = 1.78712\times10^{-17}\text{ J}$ $v = \sqrt{\frac{2\times1.78712\times10^{-17}\text{J}}{9.11\times10^{-31}\text{ kg}}} = 6.26\times10^{6}\text{ m s}^{-1}$	**2**

Mark Scheme

Q1.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Conversion of MeV to J (1) • See $Q_1 = 79 \times 1.6 \times 10^{-19}$ and $Q_2 = 2 \times 1.6 \times 10^{-19}$ (1) • Use of $V = \frac{Q}{4\pi\varepsilon_0 r}$ and $W = QV$ (1) • $r = 4.1\times10^{-14}$ m (1)	Example of calculation $E_\alpha = 5.5\times10^{6}\text{eV}\times1.6\times10^{-19}\text{J eV}^{-1} = 8.8\times10^{-13}\text{J}$ $8.8\times10^{-13}\text{J} = \frac{79\times1.6\times10^{-19}\text{C}\times2\times1.6\times10^{-19}\text{C}}{4\pi\times8.85\times10^{-12}\text{ F m}^{-1}\ r}$ $r = \frac{3.64\times10^{-26}\text{ N m}^2}{8.8\times10^{-13}\text{ J}} = 4.1\times10^{-14}\text{ m}$	4
(ii)	• Electrons are behaving like waves (1) • wavelength $= \frac{h}{\text{momentum}}$ (1) • Electron wavelength must be similar to the atomic spacing in the foil (1)	MP3: Accept electron wavelength must be similar to the distance between (adjacent) nuclei	3

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	• Line of best fit drawn (1) • Gradient determined (1) • Applies eV to J conversion factor (1) • $h = 6.62\times10^{-34}$ J s (6.4×10^{-34} J s to 6.8×10^{-34} J s) (1) MP4 dependent on calculation from graph	Example of calculation Gradient = 4.14×10^{-15} $h = 4.14\times10^{-15}$ eV s $\times 1.6\times10^{-19}$ J eV^{-1} $h = 6.62\times10^{-34}$ J s	4

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• x-intercept determined (1) • Use of $\phi = hf_0$ (1) • $\phi = 2.3$ eV, so metal is (probably) caesium (allow ecf for h from (a)) (1) **OR** • Reads a pair of co-ordinates from graph • Use of $\phi = hf - E$ • $\phi = 2.3$ eV, so metal is (probably) caesium (allow ecf for h from (a))	MP2: allow use of standard value for h or value of h determined in (a) <u>Example of calculation</u> $f_0 = 55 \times 10^{13}$ Hz $\phi = 6.62\times10^{-34}$ J s $\times 55\times10^{13}$ Hz $=3.64\times10^{-19}$ J $\phi = \frac{3.64 \times 10^{-19}\text{J}}{1.6 \times 10^{-19}\text{ J eV}^{-1}} = 2.28$ eV	3

Q4.

Question Number	Answer		Mark
(a)	photon absorbed by electron electron moves to higher energy level **Or** electron excited where photon energy = difference in energy levels only certain changes/differences possible between discrete energy levels	(1) (1) (1) (1) (1)	5
(b)(i)	Use of $E = hf$ Use of conversion factor to eV Energy of photon = 1.91 (eV) Identify levels 3.41 (eV) and 1.51 (eV) **Or** levels 1 and 2 Example of calculation $E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz (= 3.05×10^{-19} J) $E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz $\div$ 1.6×10^{-19} J s = 1.91 eV = 3.41 eV − 1.51 eV (1.90 eV) as the closest match	(1) (1) (1) (1)	4
(b)(ii)	Just-free electrons have zero energy state **Or** energy value of level $n = \infty$ is 0 (Bound) electrons need to gain energy to attain this state **Or** electrons need to gain energy to move to a higher level (Accept Because they must gain energy to move up for second mark) (accept answers in terms of ionisation energy)	(1) (1)	2
(c)	Look for corresponding pattern of lines / frequency spacings at different place in spectrum **Or** reference to known normal positions moving away increases observed wavelength / decreases frequency (or the case for moving towards) so if shifted to red end then moving away (or blue = towards) **Or** the greater the velocity the greater the change in frequency	(1) (1) (1)	3
	Total for question		**14**

Q5.

Question Number	Answer	Additional Guidance	Mark
	Use of $E = hf$ **and** $v = f\lambda$ (1) Conversion eV to J (1) $\lambda = 2.9 \times 10^{-7}$ m (1)	Example of calculation $\lambda = \frac{6.63\times10^{-34}\text{J s} \times 3.0\times10^{8}\text{m s}^{-1}}{4.3\text{ eV}\times 1.6\times10^{-19}\text{ C}} = 289$ nm	3

Q6.

Question Number	Answer	Mark
(a)	The wavelength (associated) with a particle/electron (1) with a given momentum (1) **Or** $\lambda = h/p$ (1) all terms defined (1)	**2**
(b)(i)	Use of $E_k = eV$ (1) Use of $E_k = p^2/2m$ **Or** use of $E_k = mv^2/2$ **and** $p = mv$ (1) Momentum = 1.21×10^{-23} kg m s^{-1} (1) Example of calculation $E_k = 1.6 \times 10^{-19}$ C× 500 V $p^2 = 2\,m\,E_k = 2 \times 9.11 \times 10^{-31}$ kg × $(1.6 \times 10^{-19} \times 500)$ J $p = 1.21 \times 10^{-23}$ kg m s^{-1}	**3**
(b)(ii)	Use of $\lambda = h/p$ (1) $\lambda = 5.49 \times 10^{-11}$ m (ecf value of p from (i)) (1) (show that value gives 6.63×10^{-11} m) Example of calculation $p = 6.63 \times 10^{-34}$ J s / 1.21×10^{-23} kg m s^{-1} $\lambda = 5.49 \times 10^{-11}$ m	**2**
	Total for question	7

Q7.

Question Number	Answer	Mark
(a)	Lowest / minimum frequency (of light / photons incident on a metal) that will cause electrons to be emitted (from surface) **Or** the frequency of (light / photons) that will cause electrons to be emitted (from the surface of a metal) with zero kinetic energy (1) (accept only just emitted)	**1**
(b)	Conversion of eV to J (1) Use of $E = hf$ (1) $f = 5.5 \times 10^{14}$ Hz (1) Example of calculation $\varphi = (2.28$ eV × 1.6×10^{-19} C) $= 3.65 \times 10^{-19}$ J $f = 3.65 \times 10^{-19}$ J / 6.63×10^{-34} J s = 5.50×10^{14} Hz	**3**
	Total for Question	**4**

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	the lowest frequency (of incident radiation) that will cause the emission of (photo)electrons (from the surface)		**(1)**

Question Number	Acceptable answers		Additional guidance	Mark
(b)	• use of ½ m v_{max}^2	(1)	Example of calculation: E = 6.63 × 10^{-34} J s × 8.9 × 10^{14} Hz = 5.9 × 10^{-19} J	
	• use of $\varphi = hf$ – max ke	(1)	½ m v_{max}^2 = ½ × 9.11 × 10^{-31} kg × (6.7 × 10^5 m s^{-1})^2 = 2.045 × 10^{-19} J φ = 5.9 × 10^{-19} J – 2.045 × 10^{-19} J = 3.8 × 10^{-19} J	
	• divides energy in joule by 1.6 × 10^{-19} C	(1)	= 1.8 × 10^{-19} J ÷ 1.6 × 10^{-19} C	
	• φ = 2.4 eV	(1)	= 2.4 eV	**(4)**

Q9.

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

Q10.

Question Number	Answer	Mark
	D	**1**
	Incorrect Answers: A – absorption of the longest wavelength B – emission with the longest wavelength C – absorption of the shortest wavelength	

Q11.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $E = hf$ and $c = f\lambda$ **(1)** • Convert J to eV **(1)** • 2.1 eV **(1)** • Arrow drawn on diagram from −3.04 eV to −5.14 eV **(1)**	Example of calculation $E = 6.63 \times 10^{-34}$ Js $\times 3.00 \times 10^{8}$ m s^{-1} / 5.89×10^{-7} m $= 3.38 \times 10^{-19}$ J 3.38×10^{-19} J / 1.60×10^{-19} C = 2.11 eV	4

Q12.

Question Number	Answer	Mark
	B ground state to level 2	**1**
	Incorrect Answers: A – incorrect change in energy C – incorrect change in energy and direction D – incorrect direction	

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
	• attempt to determine mass difference between radium and radon-plus-alpha (1) • conversion to kg (1) • Use of $\Delta E = c^2\Delta m$ (1) • Use of 1.6×10^{-19} factor (1) • Answer = 4.87 (MeV) (1)	$\Delta m = 225.97713\text{u} - (221.97040\text{u} + 4.00151\text{ u})$ $= 5.22 \times 10^{-3}\text{ u} = 5.22 \times 10^{-3} \times 1.66 \times 10^{-27}\text{ kg} = 8.67 \times 10^{-30}\text{ kg}$ $\Delta E = c^2\Delta m = (3 \times 10^8\text{ m s}^{-1})^2 \times 8.67 \times 10^{-30}\text{ kg} = 7.80 \times 10^{-13}\text{ J}$ ΔE in MeV $= 7.80 \times 10^{-13}\text{ J} \div 1.6 \times 10^{-19}\text{ C}$ $= 4.87$ MeV	5

Q14.

Question Number	Answer	Mark
	electron emitted by absorption of light/UV/photon (1) one photon absorbed by one electron (1) if frequency above threshold frequency then electron emitted **Or** if photon energy above work function energy then electron emitted (1) Use of $hf = \varphi$ (using work function to find corresponding frequency or wavelength) **Or** Use photon energy = hf (using any identified frequency or wavelength of visible light or UV to find corresponding photon energy) (1) Threshold frequency = 1.0×10^{15} Hz **Or** wavelength = 2.9×10^{-7} m **Or** Photon energy for light = a value between 2.9×10^{-19} J and 5.1×10^{-19} J **Or** photon energy for UV = a value between 5.1×10^{-19} J and 1.99×10^{-17} J (1) State visible light frequency too low / wavelength too long **Or** compare photon energy to work function (1) Example of calculation $f = 6.88 \times 10^{-19}\text{ J} \div 6.33 \times 10^{-34}\text{ J s}$ $= 1.0 \times 10^{15}$ Hz	6
	Total for question	**6**

Q15.

Question number	Acceptable answers	Additional guidance	Mark
(i)	• use of $F = Q_1Q_2/4\pi\varepsilon_0 r^2$ **(1)** • use of $F = Gm_1m_2/r^2$ **(1)** • Expresses forces as a ratio **(1)** **OR** calculates the individual forces $F_e = 8.1 \times 10^{-8}$ N $F_g =$ • 3.6×10^{-47} N **(1)** • Ratio = 2×10^{39} or 5×10^{-40} and identifies gravitational force as insignificant **(1)**		**4**
(ii)	• use of $F = mv^2/r$ and $F = Q_1Q_2/4\pi\varepsilon_0 r^2$ **(1)** • to derive $v = \sqrt{\frac{Q_1Q_2}{4\pi\epsilon_0 rm}}$ **(1)** • velocity = 2.2×10^6 m s^{-1} **(1)**	Example of calculation: $v = \sqrt{\frac{Q_1Q_2}{4\pi\epsilon_0 rm}}$ $v = \sqrt{\frac{1.6\times10^{-19}\text{ C}\times1.6\times10^{-19}\text{ C}}{4\pi\times8.85^{-12}\text{ F}m^{-1}\times5.3\times10^{-11}\text{m}\times9.1\times10^{-31}\text{ kg}}}$ $v = 2.185 \times 10^6$ m s^{-1}	**3**

Q16.

Question Number	Answer	Mark
	A	**1**

Q17.

Question Number	Answer		Mark
(a)	Oscillations/vibrations (of molecules) parallel to direction of propagation **Or** oscillations parallel to direction of wave travel **Or** oscillations parallel to direction of energy transfer Produces compressions and rarefactions	(1) (1)	2
(b)	Otherwise there wouldn't be a way of telling which bit of reflected sound originated with which bit of emitted sound **Or** so one returns before one emitted	 (1)	1
(ci)	time (= 1÷16 Hz) = 0.063 (s) (at least 2 sf)	(1)	1
(cii)	Use of factor of 2 Use of $v = s/t$ distance = 48 m (Use of 'show that' value gives 46m) <u>Example of calculation</u> 2 × distance = 1530 m s^{-1} × 0.063 s distance = 48 m	(1) (1) (1)	3
(ciii)	A shorter time between clicks because the distance is shorter **Or** more frequent clicks allow rapid motion to be perceived. **Or** allow position to be determined precisely/accurately.	 (1)	1
(d)	Speed in air lower than speed in water So wavelength in air shorter than wavelength in water **Or** pulse length in air is shorter than pulse length in water **Or** attempt at numerical comparison of wavelength or pulse length So bat echolocation will detect smaller targets **Or** detect smaller differences in position (conditional on MP2) (Accept 'show more detail' or 'better resolution')	(1) (1) (1)	3
	Total for question		11

Q18.

Question Number	Answer	Mark
(a)	**When illuminated:** Use of the word photon (1) photons/light cause emission of (photo)electrons (1) Idea that (photo) electrons form a current (1) photon energy greater than or equal to work function. (1) **In darkness:** No photons so no photoelectrons released (1)	**5**
(b)	Use of $E = hf$ (1) Conversion of eV to J (1) One of the 4 values below correct $f = 5.2 \times 10^{14}$ Hz or $\lambda = 5.8 \times 10^{-7}$ m for caesium $f = 8.8 \times 10^{14}$ Hz or $\lambda = 3.4 \times 10^{-7}$ m for zinc (1) Comment that Cs is in the visible range or Zn is ultraviolet – allow even without supporting calculation (1) **Alternative method** Allow assumed max freq/min wavelength for visible light then, calculation of work function, quoted in eV, comparison with given work functions, conclusion: Use of (1); work fn (1), in eV (1), comparison (1) Example of calculation $f = \varphi \div h = (2.14 \times 1.6 \times 10^{-19})$ J $\div$ 6.63×10^{-34} J s $= 5.2 \times 10^{14}$ Hz for caesium $f = \varphi \div h = (3.63 \times 1.6 \times 10^{-19})$ J $\div$ 6.63×10^{-34} J s $= 8.8 \times 10^{14}$ Hz for zinc	**4**
(ci)	Maximum displacement of the wave **Or** maximum displacement from the mean **Or** maximum displacement from equilibrium (1)	**1**
(cii)	**Max 3** Size of the gap (in the soundtrack) determines the amount of light (1) Amount of light determines number of photons (1) Number of photons determines number of (photo) electrons (released by phototube) (1) Number of electrons determines size of current (in the circuit) (1) (Combining MP 1 and 2 by writing "size of the gap determines number of photons" scores 1 mark. Combining MP 2 and 3 by writing "the amount of light determines number of (photo) electrons" also scores 1 mark)	**3**
	Total for question	**13**

Q19.

Question Number	Answer		Mark
(a)	Quantum of … **Or** (discrete) packet of … **Or** discrete quantity of …	**(1)**	
	(To score the mark must refer to something relevant e.g. light / energy) Of <u>electromagnetic</u> radiation/energy	**(1)**	**2**
*** (b)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)	**(1)**	
	describe relevant interaction between single photon and single electron		
	photon energy depends on frequency **Or** reference to $E = hf$ (must be link to photons/light)	**(1)**	
	if photon energy greater than work function, electron emitted (immediately)	**(1)**	
	whereas for waves energy could build up **Or** with waves that the electron can absorb energy continuously or over time	**(1)**	**5**
	so any frequency should work **Or** but this build up doesn't happen		
(c)(i)	Use of $4.3 \times 1.6 \times 10^{-19}$	**(1)**	
	Use of $E = hf$	**(1)**	
	$f = 1.0 \times 10^{15}$ Hz	**(1)**	**3**
	<u>Example of calculation</u> $E = 4.3\ \text{V} \times 1.6 \times 10^{-19}\ \text{C}$ $= 6.9 \times 10^{-19}\ \text{J}$ $6.9 \times 10^{-19}\ \text{J} = 6.63 \times 10^{-34}\ \text{Js} \times f$ $f = 1.0 \times 10^{15}$ Hz		
(c)(ii)	Ultraviolet Accept ultraviolet even if frequency in c(i) is incorrect, but allow ecf from candidate's value of frequency to appropriate part of electromagnetic spectrum	**(1)**	**1**
	Total for question		**11**

Q20.

Question Number	Answers	Mark
	The only correct answer is C ***A** is incorrect because the energy is calculated in eV* ***B** is incorrect because the mass and energy conversions are incorrect* ***D** is incorrect because the mass conversion is incorrect*	1

Q21.

Question Number	Answer		Mark
(a)(i)	4.0 Ω	(1)	1
(a)(ii)	Use of $V=IR$ I = 0.75 A (ecf) Example of calculation I= 3 V / 4 Ω I= 0.75 A	(1) (1)	2
(a)(iii)	Use of $P = I^2R$ **or** $P = VI$ **or** $P=V^2/R$ Power = 2.0 W (ecf) Example of calculation $P = (0.75\ A)^2 \times 3.6\ \Omega$ P= 2.0 W	(1) (1)	2
(b)	Total resistance (of circuit) will increase Current will decrease Reference to $P = I^2R$ to explain power decreasing **Or** $P = VI$ to explain power decreasing **Or** Lost volts increases **Or** Ir increases V across element decreases Reference to $P = VI$ to explain power decreasing **Or** $P=V^2/R$ to explain power decreasing	(1) (1) (1) (1) (1) (1)	3

Q22.

Question Number	Acceptable Answers		Additional guidance	Mark
	• Use of $E = hf$ and $v = f\lambda$ • Converts between eV to J • $\lambda = 2.0 \times 10^{-7}$ (m) **and** conclusion that superradiance can occur	(1) (1) (1)	Example of calculation E=6.2 eV × 1.6×10^{-19} C $E = \frac{6.63 \times 10^{-34}\ \text{Js} \times\ 3.0 \times 10^{8}\ \text{ms}^{-1}}{\lambda}$ λ = 201 nm so superradiance can occur	3

Q23.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• (UV radiation consists of) photons • One photon interacts with one electron **Or** energy of photon depends on frequency • Electrons released if energy (of photon) greater than work function **Or** frequency is greater than threshold frequency **Or** <u>energy</u> supplied is sufficient to remove electron	(1) (1) (1)	Accept quanta/packets of energy	3

Question Number	Acceptable answers		Additional guidance	Mark
(b)(i)	• when slider at the bottom - reading on voltmeter is zero **Or** minimum resistance - reading on voltmeter is zero • When slider at the top – reading on voltmeter is 1.5 V **Or** maximum resistance - reading on voltmeter is 1.5 V • Potential difference split between top and bottom part of resistor (either side of slider) **Or** reading on voltmeter depends on the ratio of resistances (either side of slider) **Or** moving the slider changes the resistance that the voltmeter is across	(1) (1) (1)		3

Question Number	Acceptable answers		Additional guidance	Mark
(b)(ii)	Maximum Kinetic Energy of electron = 0.6 (eV)	(1)		1

Question Number	Acceptable answers		Additional guidance	Mark
(c)	**Max 4** Valid because: • Moon and photocell both have vacuum • Both demonstration and theory use photoelectric effect Not valid because: • Different wavelengths in each case • On the moon there is dust not metal • Dust is free to move but the metal plate is fixed • On the moon UV removes electrons from (individual) atoms **and** in the demo light removes electrons from metal surface • Demonstration is based on photoelectric effect but effect on moon could be ionisation	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	Full marks can only be scored if a correct link is made between at least one physics point and the demonstration being valid or not valid Accept the same concept for photoelectric effect Accept one uses light the other UV Accept different materials for MP4	**4**

Q24.

Question Number	Answer	Mark
	A	1

Q25.

Question Number	Acceptable answers	Additional guidance	Mark
	• Draws one labelled scaled vector (either pion or muon) **(1)** • start of muon line should begin at start of pion line **Or** end of muon line should coincide with end of pion line **(1)** • angle between them should be approx 30° **(1)** • p of antineutrino = 9.5×10^{-20} N s ± 0.5×10^{-20} N s **(1)** • angle of antineutrino with muon = 150° ± 5° **Or** angle of antineutrino with pion = 120° ± 5° **(1)**	Label can be "pion" or momentum value. The line should be straight and have an arrow. 	**5**

Mark Scheme

Q1.

Question Number	Answer		Mark
(a)*	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Electrons/atoms move to higher energy levels / get excited They then move to lower energy levels (accept ground state) The energy from the move is given out in the form of a photon The energy levels are discrete **Or** only certain energy levels are possible The energy of the photon must be equal to the difference in energy levels **Or** $hf = E_2 - E_1$ There are only a limited number of energy differences and only a corresponding number of frequencies (looking for differences /changes **not** levels) (The marks above may be obtained from a suitably labelled diagram – but the order of excitation and de-excitation cannot be assumed for two marks just from the presence of both)	(1) (1) (1) (1) (1) (1)	6
(b)	Doppler (accept blue shift) The wavelength of the radiation is decreased / frequencies increases Star moving towards Earth or vice versa	(1) (1) (1)	3
(c)	Light behaves as both particle and wave **Or** wave-particle duality	(1)	1
	Total for question		10

Q2.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• (for deoxygenated blood) μ is greater for red • hence more red is absorbed **Or** intensity is smaller for red **Or** $e^{-\mu x}$ is smaller for red • So I/I_0 is smaller for red [dependent upon MP2]	(1) (1) (1)	Accept values for μ which show $\mu_{red} > \mu_{IR}$ for MP1 Allow numerical substitutions for MP2 and MP3 Accept converse argument leading to same conclusion	3

Q3.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• μ read from graph	(1)	Accept μ in the range 140 (m^{-1}) - 160 (m^{-1})	3
	• Use of $I = I_0 e^{-\mu x}$	(1)		
	• $I = 1.5$ W m^{-2}	(1)	Accept answers that round to 1.4 W m^{-2} or 1.5 W m^{-2} dependent upon value of μ for MP3 Example of calculation: I=1.8 W m^{-2} $\times e^{-150\ m^{-1} \times 1.4 \times 10^{-3}\ m}$ = 1.46 W m^{-2}	

Q4.

Question Number	Answer		Mark
	electron emitted by absorption of light/UV/photon	(1)	
	one photon absorbed by one electron	(1)	
	if frequency above threshold frequency then electron emitted **Or** if photon energy above work function energy then electron emitted	(1)	
	Use of $hf = \varphi$ (using work function to find corresponding frequency or wavelength) **Or** Use photon energy = hf (using any identified frequency or wavelength of visible light or UV to find corresponding photon energy)	(1)	
	Threshold frequency = 1.0×10^{15} Hz **Or** wavelength = 2.9×10^{-7} m **Or** Photon energy for light = a value between 2.9×10^{-19} J and 5.1×10^{-19} J **Or** photon energy for UV = a value between 5.1×10^{-19} J and 1.99×10^{-17} J	(1)	
	State visible light frequency too low / wavelength too long **Or** compare photon energy to work function	(1)	6
	Example of calculation $f = 6.88 \times 10^{-19}$ J $\div$ 6.33×10^{-34} J s $= 1.0 \times 10^{15}$ Hz		
	Total for question		6

Q5.

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>(i)</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 rowspan="2">Guidance on how the mark scheme should be applied:

The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).</td><td></td></tr>
<tr><td></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>

Indicative content
• photon energy discrete/quantised
</td><td></td></tr>
</table>

	• one photon transfers all of its energy to one electron **Or** one photon cause the emission of one (photo)electron • photon must have energy greater than / equal to work function energy to release (photo)electron • reference to $E = hf$ • if light was a wave, energy could build up • if light was a wave, any frequency could provide sufficient energy in time there would be a current for all frequencies		**(6)**

Q6.

Question Number	Answer	Additional Guidance	Mark
	• one photon interacts with one electron (1) • when the energy of the photon is equal to or greater than the work function (of the metal) an electron is released (1) • energy of photon = hf so there is a minimum/threshold frequency (1)		**3**

Q7.

Question Number	Acceptable answer	Additional guidance	Mark
	D	The only correct answer is **D**: a wave of greater intensity would still transfer energy at a greater rate which could release photoelectrons at a greater rate even if they could absorb energy continuously A is not correct because time would be required for absorption of sufficient wave energy B is not correct because absorption of sufficient wave energy would occur over time C is not correct because at higher intensities the waves would have higher amplitudes and energy could increase over time to higher values	1

Q8.

<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><th>Max linkage mark available</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
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</td>
<td></td>
</tr>
<tr>
<td></td>
<td>
Indicative content

Observations

• Photoelectrons emitted instantaneously when radiation incident on surface
• There is no photoemission below the threshold frequency
• The maximum ke of the photoelectrons is independent of the intensity of the incident radiation
• The rate of photoemission is proportional to the intensity of the incident radiation

Models
• One photon is absorbed by one electron
Or all of the energy of one photon is transferred to one electron
• With waves, energy can be supplied to the electron continuously
Or with waves, energy can 'build up'
</td>
<td>
There are 4 observations and 2 models. Linkage is demonstrated by linking observations and models.

Two linkage marks can only be awarded if reference is made to both models and more than one observation
</td>
<td>6</td>
</tr>
</table>

Q9.

Question Number	Answer		Mark
(a)	Quantum of … **Or** (discrete) packet of … **Or** discrete quantity of …	**(1)**	
	(To score the mark must refer to something relevant e.g. light / energy) Of <u>electromagnetic</u> radiation/energy	**(1)**	**2**
*** (b)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)	**(1)**	
	describe relevant interaction between single photon and single electron		
	photon energy depends on frequency **Or** reference to $E = hf$ (must be link to photons/light)	**(1)**	
	if photon energy greater than work function, electron emitted (immediately)	**(1)**	
	whereas for waves energy could build up **Or** with waves that the electron can absorb energy continuously or over time so any frequency should work **Or** but this build up doesn't happen	**(1)**	**5**
(c)(i)	Use of $4.3 \times 1.6 \times 10^{-19}$	**(1)**	
		(1)	
	Use of $E = hf$ $f = 1.0 \times 10^{15}$ Hz	**(1)**	**3**
	<u>Example of calculation</u> $E = 4.3\ \text{V} \times 1.6 \times 10^{-19}\ \text{C}$ $= 6.9 \times 10^{-19}\ \text{J}$ $6.9 \times 10^{-19}\ \text{J} = 6.63 \times 10^{-34}\ \text{Js} \times f$ $f = 1.0 \times 10^{15}$ Hz		
(c)(ii)	Ultraviolet Accept ultraviolet even if frequency in c(i) is incorrect, but allow ecf from candidate's value of frequency to appropriate part of electromagnetic spectrum	**(1)**	**1**
	Total for question		**11**

Q10.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• (UV radiation consists of) photons • One photon interacts with one electron **Or** energy of photon depends on frequency • Electrons released if energy (of photon) greater than work function **Or** frequency is greater than threshold frequency **Or** <u>energy</u> supplied is sufficient to remove electron	(1) (1) (1)	Accept quanta/packets of energy	3

Question Number	Acceptable answers		Additional guidance	Mark
(b)(i)	• when slider at the bottom - reading on voltmeter is zero **Or** minimum resistance - reading on voltmeter is zero • When slider at the top – reading on voltmeter is 1.5 V **Or** maximum resistance - reading on voltmeter is 1.5 V • Potential difference split between top and bottom part of resistor (either side of slider) **Or** reading on voltmeter depends on the ratio of resistances (either side of slider) **Or** moving the slider changes the resistance that the voltmeter is across	(1) (1) (1)		3

Question Number	Acceptable answers		Additional guidance	Mark
(b)(ii)	Maximum Kinetic Energy of electron = 0.6 (eV)	(1)		1

Question Number	Acceptable answers		Additional guidance	Mark
(c)	**Max 4** Valid because: • Moon and photocell both have vacuum • Both demonstration and theory use photoelectric effect Not valid because: • Different wavelengths in each case • On the moon there is dust not metal • Dust is free to move but the metal plate is fixed • On the moon UV removes electrons from (individual) <u>atoms</u> **and** in the demo light removes electrons from metal <u>surface</u> • Demonstration is based on photoelectric effect but effect on moon could be ionisation	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	Full marks can only be scored if a correct link is made between at least one physics point and the demonstration being valid or not valid Accept the same concept for photoelectric effect Accept one uses light the other UV Accept different materials for MP4	**4**

Mark Scheme

Q1.

Question Number	Answer		Mark
(a)	photon absorbed by electron electron moves to higher energy level **Or** electron excited where photon energy = difference in energy levels only certain changes/differences possible between discrete energy levels	(1) (1) (1) (1) (1)	5
(b)(i)	Use of $E = hf$ Use of conversion factor to eV Energy of photon = 1.91 (eV) Identify levels 3.41 (eV) and 1.51 (eV) **Or** levels 1 and 2 Example of calculation $E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz ($= 3.05 \times 10^{-19}$ J) $E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz $\div$ 1.6×10^{-19} J s = 1.91 eV = 3.41 eV − 1.51 eV (1.90 eV) as the closest match	(1) (1) (1) (1)	4
(b)(ii)	Just-free electrons have zero energy state **Or** energy value of level $n = \infty$ is 0 (Bound) electrons need to gain energy to attain this state **Or** electrons need to gain energy to move to a higher level (Accept Because they must gain energy to move up for second mark) (accept answers in terms of ionisation energy)	(1) (1)	2
(c)	Look for corresponding pattern of lines / frequency spacings at different place in spectrum **Or** reference to known normal positions moving away increases observed wavelength / decreases frequency (or the case for moving towards) so if shifted to red end then moving away (or blue = towards) **Or** the greater the velocity the greater the change in frequency	(1) (1) (1)	3
	Total for question		**14**

Q2.

Question Number	Answer		Mark
(a)*	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Electrons/atoms move to higher energy levels / get excited They then move to lower energy levels (accept ground state) The energy from the move is given out in the form of a <u>photon</u> The energy levels are discrete **Or** only certain energy levels are possible The energy of the photon must be equal to the difference in energy levels **Or** $hf = E_2 - E_1$ There are only a limited number of energy differences and only a corresponding number of frequencies (looking for differences /changes **not** levels) (The marks above may be obtained from a suitably labelled diagram – but the order of excitation and de-excitation cannot be assumed for two marks just from the presence of both)	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**6**
(b)	Doppler (accept blue shift) The wavelength of the radiation is decreased / frequencies increases Star moving towards Earth or vice versa	**(1)** **(1)** **(1)**	**3**
(c)	Light behaves as both particle and wave **Or** wave-particle duality	**(1)**	**1**
	Total for question		**10**

Q3.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• Electrons exist in discrete energy levels (1) • (After the mercury atom is excited) electrons move back to a lower energy level **Or** (After the mercury atom is excited) electrons move back down from a higher energy level (1) • Photons are emitted (1) • Frequency of emitted radiation / photons depends on the difference in energy between the energy levels **Or** reference to $\Delta E = hf$ (1) • Since there are only certain energy changes possible, only certain frequencies are possible (1)	Accept excited state for higher energy level Accept ground state for lower energy state	5

Q4.

Question Number	Answer	Additional Guidance	Mark
	Use of $E = hf$ **and** $v = f\lambda$ (1) Conversion eV to J (1) $\lambda = 2.9 \times 10^{-7}$ m (1)	Example of calculation $\lambda = \frac{6.63\times10^{-34}\text{J s} \times 3.0\times10^{8}\text{m s}^{-1}}{4.3\text{ eV}\times 1.6\times10^{-19}\text{ C}} = 289$ nm	3

Q5.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• (for deoxygenated blood) μ is greater for red	(1)	Accept values for μ which show $\mu_{red} > \mu_{IR}$ for MP1	
	• hence more red is absorbed **Or** intensity is smaller for red **Or** $e^{-\mu x}$ is smaller for red	(1)	Allow numerical substitutions for MP2 and MP3	
	• So I/I_0 is smaller for red [dependent upon MP2]	(1)	Accept converse argument leading to same conclusion	**3**

Q6.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• μ read from graph	(1)	Accept μ in the range 140 (m^{-1}) - 160 (m^{-1})	
	• Use of $I = I_0 e^{-\mu x}$	(1)		
	• $I = 1.5$ W m^{-2}	(1)	Accept answers that round to 1.4 W m^{-2} or 1.5 W m^{-2} dependent upon value of μ for MP3 Example of calculation: I=1.8 W m^{-2} $\times e^{-150\ m^{-1} \times 1.4 \times 10^{-3}\ m}$ = 1.46 W m^{-2}	**3**

Q7.

Question Number	Answer	Mark
	C	**1**

Q8.

Question Number	Answer	Additional Guidance	Mark
	electron falls back down energy levels emitting a photon (1) wavelength (of photon) is inversely proportional to the energy change (1) refers to energy transition n=3 to n=2 **or** n=2 to n=1 (1)		**3**

Q9.

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

Q10.

Question Number	Answer	Mark
	D	**1**
	Incorrect Answers: A – absorption of the longest wavelength B – emission with the longest wavelength C – absorption of the shortest wavelength	

Q11.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $E = hf$ and $c = f\lambda$ (1) • Convert J to eV (1) • 2.1 eV (1) • Arrow drawn on diagram from −3.04 eV to −5.14 eV (1)	Example of calculation $E = 6.63 \times 10^{-34}$ Js $\times 3.00 \times 10^{8}$ m s^{-1} / 5.89×10^{-7} m $= 3.38 \times 10^{-19}$ J 3.38×10^{-19} J / 1.60×10^{-19} C = 2.11 eV	4

Q12.

Question Number	Answer	Mark
	B ground state to level 2	**1**
	Incorrect Answers: A – incorrect change in energy C – incorrect change in energy and direction D – incorrect direction	

Q13.

Question Number	Answer	Mark
	D shortest arrow pointing to ground state	**1**
	Incorrect Answers: **A** – shortest wavelength absorbed **B** – longest wavelength absorbed **C** – shortest wavelength emitted	

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.

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The following table shows how the marks should be awarded for structure and lines of reasoning.</td><td>Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no</td><td></td></tr>
</table>

	Number of marks awarded for structure of answer and sustained line of reasoning	marks for linkages).	
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2		
Answer is partially structured with some linkages and lines of reasoning	1		
Answer has no linkages between points and is unstructured	0		**(6)**

Indicative content

- electrons/atoms move to higher energy levels
  Or electrons/atoms are excited
- they then move to lower energy levels (accept ground state) and the energy (from the change) is given out in the form of a photon

	• the energy levels are discrete **Or** only certain energy levels are possible • the energy of the photon is equal to the difference in energy levels **Or** $hf = E_2 - E_1$ **Or** $hc/\lambda = E_2 - E_1$ • there are only a limited number of energy differences and only a corresponding set of frequencies/wavelengths • different elements have different energy level (differences), so they will produce different frequencies/wavelengths	looking for energy differences /changes **not** energy levels	

Q15.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• the atoms have discrete energy levels (1) • atoms gain energy and get excited / electrons move to higher energy levels (1) • atoms/electrons move to lower energy levels and emit energy as photons (1) • <u>different</u> energy changes cause photons with <u>different</u> frequencies/wavelengths (1)		**(4)**

Q16.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• (Moving) electrons collide with lattice/ions (1) • Transfer of energy to (lattice) ions so they vibrate with larger amplitude/speed (and the temperature increases) (1)		2
(ii)	• Electrons/ions in the tube collide with mercury/phosphor atoms and excite electrons (in the mercury/phosphor atoms) (1) • Energy is released in the form of photons as the electrons move back down (to the ground state) (1)	Mention of work function scores 0 MP2 Allow de-excite for move back down	2

Q17.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Electrons are excited to higher energy states / levels (by incident electrons)	(1)	For MP1 and MP2 allow • Electrons knock electrons out of low energy levels • Electrons cascade down to fill up the levels	4
	• An electron returns to the lower energy state / level resulting in the emission of a <u>photon</u>	(1)		
	• The energy of the photon is equal to the difference of the energy states / levels	(1)		
	• Large difference in energy states / levels so as $E = hf$, radiation is high frequency	(1)		

Q18.

Question Number	Acceptable answers	Additional guidance	Mark
*	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning		6

IC points	IC mark	Max structure mark	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

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.

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

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

IC5 and IC6 can be awarded if suitable equations with terms explained are used

	Indicative content IC1 Electrons in neon atoms/molecules absorb <u>energy</u> due to electron collisions **Or** neon atoms/molecules absorb <u>energy</u> due to electron collisions IC2 Electrons in neon atoms/molecules move to higher energy levels/states **Or** Electrons in neon atoms/molecules are excited **Or** Neon atoms/molecules are excited IC3 A <u>photon</u> is released when an electron drops down energy levels **Or** A <u>photon</u> is released when an atoms/electron de-excites IC4 Electrons/atoms/molecules have discrete energy levels/states IC5 Frequency/wavelength (of emitted photon) is determined by difference in energy levels/states **Or** $E_2-E_1 = hf$ where is f is frequency IC6 Limited number of possible energy levels/states, and so only certain/particular/specific frequencies/ wavelengths are emitted **Or** Only certain energy changes possible, and so only certain/particular/specific frequencies/ wavelengths are emitted		

Q19.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Use of $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ (1) • mean kinetic energy $= 6.4\times10^{-20}$J (1)	Example of calculation: $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ $= \frac{3}{2}\times1.38\times10^{-23}\text{JK}^{-1}\times3100\text{K} = 6.42\times10^{-20}\text{J}$	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• There are electron transitions between energy levels in the atoms, (1) • When electrons return to a lower level they emit energy in the form of photons (1)		2

Q20.

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

(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 $\sin\theta$ 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

Q21.

Question Number	Acceptable Answers		Additional Guidance	Mark
	• atoms/electrons have fixed/discrete/specific energy levels	(1)	Answers in terms of emission spectrum can be awarded MP1, 4 and 5	5
	• electrons get excited by absorbing <u>photons</u>	(1)		
	• energy of <u>photon</u> absorbed = difference in energy levels	(1)		
	• only certain transitions possible, so only certain <u>photon</u> energies absorbed so only certain frequencies missing	(1)		
	• the set of frequencies absorbed depends on the element	(1)		

Q22.

Question Number	Acceptable Answers		Additional guidance	Mark
	Max 6 **Similarities** • An electron absorbs a photon **Or** electrons gain energy from a photon (1) • photons need a minimum amount of energy (1) • So light must be above a certain frequency (1) • increasing the light intensity increases the number of electrons (released per sec) (1) • Evidence for the particle model of light (1) **Differences** • In the photoelectric effect electrons are released from the surface (1) • But electrons remain within the LDR (1) • Photoelectric effect occurs in metals **Or** LDR is a semiconductor (1)			**6**

Q23.

Question Number	Answer		Mark
(a)	Quantum of … **Or** (discrete) packet of … **Or** discrete quantity of …	**(1)**	
	(To score the mark must refer to something relevant e.g. light / energy) Of <u>electromagnetic</u> radiation/energy	**(1)**	**2**
*** (b)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)	**(1)**	
	describe relevant interaction between single photon and single electron		
	photon energy depends on frequency **Or** reference to $E = hf$ (must be link to photons/light)	**(1)**	
	if photon energy greater than work function, electron emitted (immediately)	**(1)**	
	whereas for waves energy could build up **Or** with waves that the electron can absorb energy continuously or over time	**(1)**	**5**
	so any frequency should work **Or** but this build up doesn't happen		
(c)(i)	Use of $4.3 \times 1.6 \times 10^{-19}$	**(1)**	
	Use of $E = hf$	**(1)**	
	$f = 1.0 \times 10^{15}$ Hz	**(1)**	**3**
	<u>Example of calculation</u> $E = 4.3\ \text{V} \times 1.6 \times 10^{-19}\ \text{C}$ $= 6.9 \times 10^{-19}\ \text{J}$ $6.9 \times 10^{-19}\ \text{J} = 6.63 \times 10^{-34}\ \text{Js} \times f$ $f = 1.0 \times 10^{15}$ Hz		
(c)(ii)	Ultraviolet Accept ultraviolet even if frequency in c(i) is incorrect, but allow ecf from candidate's value of frequency to appropriate part of electromagnetic spectrum	**(1)**	**1**
	Total for question		**11**

Q24.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• Use of $E = \frac{1}{2}mv^2$ (1) • Use of $E = hf$ **and** $c = f\lambda$ (1) • $\lambda = (2.4 - 2.5) \times 10^{-7}$ (m) (1) • leading to a conclusion that radiation is ultraviolet **Or** conclusion consistent with their value for wavelength (1)	MP4 dependent on MP2 Example of Calculation $\Delta E_k = \frac{1}{2} \times 9.11 \times 10^{-31}\ \text{kg} \times ((2.5 \times 10^6\ \text{m s}^{-1})^2 - (2.1 \times 10^6\ \text{m s}^{-1})^2)$ $\Delta E_k = 8.4 \times 10^{-19}$ (J) $\lambda = \frac{6.63 \times 10^{-34}\ \text{J s} \times 3 \times 10^8\ \text{m s}^{-1}}{8.4 \times 10^{-19}\ \text{J}}$ $\lambda = 2.4 \times 10^{-7}$ (m)	4

Q25.

Question Number	Answer		Mark
(a)(i)	4.0 Ω	**(1)**	**1**
(a)(ii)	Use of $V=IR$ I = 0.75 A (ecf) Example of calculation I= 3 V / 4 Ω I= 0.75 A	**(1)** **(1)**	**2**
(a)(iii)	Use of $P = I^2R$ **or** $P = VI$ **or** $P=V^2/R$ Power = 2.0 W (ecf) Example of calculation P = (0.75 A)^2 x 3.6 Ω P= 2.0 W	**(1)** **(1)**	**2**
(b)	Total resistance (of circuit) will increase Current will decrease Reference to $P = I^2R$ to explain power decreasing **Or** $P = VI$ to explain power decreasing **Or** Lost volts increases **Or** Ir increases V across element decreases Reference to $P = VI$ to explain power decreasing **Or** $P=V^2/R$ to explain power decreasing	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**3**