

Mark Scheme

Q1.

Question Number	Answer	Mark
	A is the correct answer as the correct rearrangement of the de Broglie equation is $v = h / \lambda m$ B is not the correct answer as this is an incorrect rearrangement of the equation C is not the correct answer as this is an incorrect rearrangement of the equation D is not the correct answer as this is an incorrect rearrangement of the equation	(1)

Q2.

Question Number	Answer	Mark
	C is the correct answer as the photoelectric effect can only be explained using the photon model of light. A is not the correct answer as diffraction is demonstrated using waves B is not the correct answer as the Huygen's construction is demonstrated using waves D is not the correct answer as plane polarisation is demonstrated using waves	(1)

Q3.

Question Number	Answer	Mark
	The only correct answer is B $\left(\frac{6.63 \times 10^{-24}}{9.11 \times 10^{-31} \times 2 \times 10^7} \right)$ A is not correct because $\lambda = \frac{h}{mv}$ and this is using mass of proton C is not correct because $\lambda = \frac{h}{mv}$ and this is $\lambda = \frac{mv}{h}$ D is not correct because $\lambda = \frac{h}{mv}$ and this is t is upside down and uses mass of proton not electron	1

Q4.

Question Number	Answer	Mark
	A is the correct answer (de Broglie wavelength = 2.43×10^{-9} m) B is not the correct answer as the de Broglie wavelength = 1.82×10^{-9} m C is not the correct answer as the de Broglie wavelength = 1.13×10^{-12} m D is not the correct answer as the de Broglie wavelength = 9.93×10^{-13} m	(1)

Q5.

Question Number	Answer	Mark
	A is the correct answer (Evidence for the wave nature of electrons came from experiments involving diffraction) B is not the correct answer C is not the correct answer D is not the correct answer	(1)

Q6.

Question Number	Answer	Mark
	Electrons can behave as waves (1)	
	Because the rings show diffraction / interference (1)	2
	Total for question	2

Q7.

Question Number	Answer	Mark
	Use of $p = mv$ (1)	3
	Use of $\lambda = \frac{h}{p}$ (1)	
	$\lambda = 2.0 \times 10^{-11} \text{ m}$ (1)	
	<u>Example calculation</u> $p = 9.11 \times 10^{-31} \text{ kg} \times 3.6 \times 10^7 \text{ m s}^{-1} = 3.28 \times 10^{-23} \text{ kg m s}^{-1}$ $\lambda = \frac{6.63 \times 10^{-34} \text{ J s}}{3.28 \times 10^{-23} \text{ kg m s}^{-1}} = 2.02 \times 10^{-11} \text{ m}$	
	Total for question	3

Q8.

Question Number	Answer	Mark
	Use of $\lambda = h/p$ (1)	3
	Use of $p = mv$ (1)	
	$m = 9.1 \times 10^{-31} \text{ (kg)}$, so mass is that of an electron Or $m = 9.1 \times 10^{-31} \text{ (kg)}$, so equals m_e Or $m = 9.1 \times 10^{-31} \text{ (kg)}$, so yes it is (1)	
	(MP3 – Do not allow answers that suggest the calculated mass is less than that of an electron, but allow “similar”, “about the same”) <u>Example of calculation</u> $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34} \text{ J s}}{7.37 \times 10^{-10} \text{ m}} = 9.00 \times 10^{-25} \text{ kg m s}^{-1}$ $m = \frac{p}{v} = \frac{9.00 \times 10^{-25} \text{ kg m s}^{-1}}{9.89 \times 10^5 \text{ m s}^{-1}} = 9.10 \times 10^{-31} \text{ kg}$	
	Total for question	3

Q9.

Question Number	Answer	Mark
	For the electron (in the atom) to move from -13.6eV to -1.5eV requires 12.1eV (1)	
	0.2eV / remaining (kinetic) energy left for the (incoming) electron (1)	
	Idea that <u>energy</u> of a photon is transferred to a single electron Or Idea that photon can only excite an electron if it matches the energy difference between levels Or Idea that photons give all of their energy (or none at all) (1)	
	Photon energy is not exactly 12.1eV so electron/atom remains at the -13.6eV level Or There is no transition equivalent to 12.3 eV Or There is no -1.3 eV energy level (1)	4
	(Ignore references to work function or photons being emitted) (MP1 – award this mark if 12.1eV is seen) (MP3 – do not award simply for saying “one photon interacts with one electron”) (MP4 – Award if candidates make it clear that 12.1eV is not equal to 12.3eV in an argument to explain why photons cannot produce the change in energy levels for the electron)	
	Total for Question	4

Q10.

Question Number	Answer	Additional Guidance	Mark
(a)	Use of $V = \frac{W}{Q}$ (1) $W = 7.68 \times 10^{-16}$ (J) Answer to at least 3 s.f. (1)	<u>Example of calculation</u> $W = 4800 \text{ V} \times 1.6 \times 10^{-19} \text{ C} = 7.68 \times 10^{-16} \text{ J}$	2
(b)	Use of $E_k = \frac{1}{2}mv^2$ ecf from (a) (1) Use of $\lambda = \frac{h}{mv}$ (1) $\lambda = 1.8 \times 10^{-11} \text{ m}$ (1)	Allow use of $E_k = \frac{p^2}{2m}$ <u>Example of calculation</u> $v = \sqrt{\frac{2 \times 7.68 \times 10^{-16} \text{ J}}{9.11 \times 10^{-31} \text{ kg}}} = 4.11 \times 10^7 \text{ m s}^{-1}$ $\lambda = \frac{6.63 \times 10^{-34} \text{ J s}}{9.11 \times 10^{-31} \text{ kg} \times 4.11 \times 10^7 \text{ m s}^{-1}} = 1.77 \times 10^{-11} \text{ m}$	3
Total for question			5

Q11.

Question Number	Answer	Mark
(a)	Use of $v = \frac{s}{t}$ (1) Halves distance or doubles time (1) Distance = 28 m (1) <u>Example of calculation</u> $s = 1500 \text{ m s}^{-1} \times 37 \times 10^{-3} \text{ s} = 55.5 \text{ m}$ $\frac{55.5 \text{ m}}{2} = 27.8 \text{ m}$	3
(b)	An echo must return to the transducer before the next pulse is transmitted (1) Or T (should be) $>$ time for the echo to return (1) So if T increases, the maximum distance increases (1)	2
(c)	Higher frequency sound waves lead to smaller wavelength (1) This gives better resolution (dependent on MP1) (1) Or Higher frequency sound waves will diffract less	2
Total for question		7

Q12.

Question Number	Answer	Mark
a	Substitutes values into $E = \left(\frac{e^2}{kh}\right)^2 \left(\frac{m}{8}\right)$ (1) Converts J into eV (1) 13.5eV or 13.6 eV (1) (MP3 is dependent upon correct working being shown) Example of calculation $E = \frac{(1.60 \times 10^{-19} \text{ C})^4 (9.11 \times 10^{-31} \text{ kg})}{(8.85 \times 10^{-12} \text{ Fm}^{-1})^2 (6.63 \times 10^{-34} \text{ Js})^2 \times 8}$ $E = 2.17 \times 10^{-18} \text{ J}$ $(2.17 \times 10^{-18} \text{ J}) / (1.60 \times 10^{-19} \text{ J eV}^{-1}) = 13.56 \text{ eV}$	3
b	Substitutes values into $r = \frac{h^2 k}{\pi m e^2}$ (1) $r = 5.3 \times 10^{-11} \text{ (m)}$ (1) Use of $\lambda = h/p$ (1) $\lambda = 2.8 \times 10^{-14} \text{ (m)}$ (for neutron) (1) neutron wavelength not similar to size of atom radius, so student is incorrect (1) (MP5 is dependent upon awarding all of MP1-4 and there needs to be some comparison of the two values) (allow MP1 and/or MP3 for candidates who substitute the incorrect mass into the equation e.g. mass of neutron where it should be mass of electron in MP1) Example of calculation $r = \frac{h^2 k}{\pi m e^2} = \frac{(6.63 \times 10^{-34} \text{ Js})^2 (8.85 \times 10^{-12})}{\pi (9.11 \times 10^{-31} \text{ kg}) (1.60 \times 10^{-19} \text{ C})^2}$ $r = 5.31 \times 10^{-11} \text{ m}$ For neutron, $\lambda = h/p = (6.63 \times 10^{-34} \text{ Js}) / (1.67 \times 10^{-27} \text{ kg}) (1.4 \times 10^7 \text{ m s}^{-1})$ $= 2.84 \times 10^{-14} \text{ m}$	5
Total for question		8

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	(Diffraction is) the spreading out of waves (1)		2
	Passing through a gap or around an object (1)	Accept slit for gap	
(b)(i)	Use of $V = \frac{W}{Q}$ (1)	Example of calculation $W = 4.9 \times 10^3 \text{ V} \times 1.6 \times 10^{-19} \text{ C}$ $= 7.84 \times 10^{-16} \text{ J}$ $v = \sqrt{\frac{7.84 \times 10^{-16} \text{ J} \times 2}{9.11 \times 10^{-31} \text{ kg}}}$ $= 4.15 \times 10^7 \text{ m s}^{-1}$ $\lambda = \frac{6.63 \times 10^{-34} \text{ J s}}{9.11 \times 10^{-31} \text{ kg} \times 4.15 \times 10^7 \text{ m s}^{-1}}$ $\lambda = 1.75 \times 10^{-11} \text{ m}$	4
	Use of $E_k = \frac{1}{2}mv^2$ (1)		
	Use of $\lambda = \frac{h}{p}$ (1)		
	$\lambda = 1.75 \times 10^{-11} \text{ (m)}$ (1)		

(b)(ii)	Converts 5000 lines per cm to slit separation (in m) (1)	Accept $\theta = (1 \times 10^{-3})^\circ$ Example of calculation $d = \frac{1}{5000} \times 10^{-2} \text{ m} = 2 \times 10^{-6} \text{ m}$ $\sin \theta = \frac{2 \times 1.8 \times 10^{-11} \text{ m}}{2 \times 10^{-6} \text{ m}} = 0.000018$ $\theta = 0.00103^\circ$	3
	Use of $n\lambda = d \sin \theta$ (1)		
	$\theta = 0.001^\circ$ (this angle is very small) so not clearly visible (allow ecf from (b)(i)) (1)		

Question Number	Answer	Mark
(a)	Use of $A = 4\pi r^2$ (1) Use of $I = P/A$ to calculate I (1) $I = 1.3 \text{ W m}^{-2} < 4.5 \text{ W m}^{-2}$ so not dangerous (1) OR Use of $A = 4\pi r^2$ (1) Use of $I = P/A$ to calculate A (1) $r = 0.13 \text{ m} < 0.25 \text{ m}$ so not dangerous (1) (For MP2 via second method, look for area of 0.22 m^2) <u>Example of calculation</u> $A = 4\pi (0.25 \text{ m})^2 = 0.79 \text{ m}^2$ $A = P/I$ so $0.79 \text{ m}^2 = 1.00 \text{ W} / I$, so $I = 1.27 \text{ W m}^{-2}$	3
(b)	Use of $E = hf$ (1) Conversion from J to eV (1) Energy per photon = $3.7 \times 10^{-6} \text{ (eV)}$ (1) <u>Example of calculation</u> $E = hf = (6.63 \times 10^{-34} \text{ Js}) \times (902 \times 10^6 \text{ Hz}) = 5.98 \times 10^{-25} \text{ J}$ Energy per photon (in eV) = $(5.98 \times 10^{-25} \text{ J}) / (1.60 \times 10^{-19} \text{ J eV}^{-1})$ $= 3.74 \times 10^{-6} \text{ eV}$.	3
(c)	Use of $P = E/t$ for kettle (1) Converts kWh to J for electricity usage Or converts J to kWh for kettle usage (1) Percentage = 0.61% so student is correct Or states that 150,000 J is less than 1% of $2.47 \times 10^7 \text{ J}$ so student is correct (1) (Kettle energy in kW h is 0.042) <u>Example of calculation</u> $E = P \times t$ (for kettle) = $1200 \text{ W} \times 125 \text{ s} = 150,000 \text{ J}$ Electricity usage = $6.85 \text{ kWh} = 6.85 \times 1000 \text{ W} \times 3600 \text{ s} = 2.47 \times 10^7 \text{ J}$ Kettle's percentage of daily usage = $[(150,000 \text{ J}) / (2.47 \times 10^7 \text{ J})] \times 100$ Percentage = 0.61%	3
	Total for Question	9

Question Number	Answer	Mark																																								
(a)(i)	Use of $E = hf$ (1) $f = 5.19 \times 10^{14} \text{ Hz}$ (1) <u>Example of calculation</u> $f = \frac{3.44 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ J s}} = 5.189 \times 10^{14} \text{ Hz}$	2																																								
* (a)(ii)	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 border="1"> <thead> <tr> <th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr> </thead> <tbody> <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> <tr><td>0</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table> The following table shows how the marks should be awarded for structure and lines of reasoning. <table border="1"> <thead> <tr> <th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr> </thead> <tbody> <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> </tbody> </table> IC1 The potential difference causes a current in the gas / tube IC2 So energy is transferred to the gas atoms IC3 Electron/atom gains (sufficient) energy to move up energy levels IC4 An (excited) electron (is unstable and) falls back down emitting a photon IC5 With a wavelength/frequency corresponding to the difference in the energy levels Or reference to $E = hf$ or $E \propto f$ IC6 Electrons/atoms exist in discrete/fixed/certain energy levels so only certain frequencies / wavelengths are emitted	IC points	IC mark	Max linkage 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		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	6
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(b)(i)	Use of $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$ (1) Use of $hf = \phi + \frac{1}{2}mv_{\text{max}}^2$ (1) $v_{\text{max}} = 5.34 \times 10^5 \text{ m s}^{-1}$ (1) <u>Example of calculation</u> $4.75 \text{ eV} \times 1.6 \times 10^{-19} \text{ J eV}^{-1} = 7.6 \times 10^{-19} \text{ J}$ $7.6 \times 10^{-19} \text{ J} = 6.3 \times 10^{-19} \text{ J} + \frac{1}{2} \times 9.11 \times 10^{-31} \text{ kg} \times v_{\text{max}}^2$ $v_{\text{max}} = 534\,000 \text{ m s}^{-1}$	3
(b)(ii)	Use of $p = mv$ and $\lambda = \frac{h}{p}$ (1) $\lambda = 1.4 \times 10^{-9} \text{ m}$ (1) <u>Example of calculation</u> $\lambda = \frac{6.63 \times 10^{-34} \text{ J s}}{9.11 \times 10^{-31} \text{ kg} \times 5.3 \times 10^5 \text{ m s}^{-1}} = 1.37 \times 10^{-9} \text{ m}$	2
Total for question		13

Q16.

Question Number	Answer	Mark
(a)	Electrons can exhibit wave behaviour (1) Electrons diffract as they pass through the graphite Or graphite acts as a diffraction grating (1) Structure of graphite must be ordered/ regular / layered (1) The (de Broglie) wavelength of the electrons is similar to the spacing of gaps between atoms (1)	4
(b)(i)	Use of $V = W/Q$ (1) $W = 3.8 \times 10^{-16} \text{ (J)}$ (1) <u>Example of calculation</u> $W = 1.6 \times 10^{-19} \text{ C} \times 2400 \text{ V} = 3.84 \times 10^{-16} \text{ J}$	2
(b)(ii)	Use of $E_k = \frac{1}{2}mv^2$ (1) $v = 2.9 \times 10^7 \text{ m s}^{-1}$ (1) (allow ecf from (b)(i)) <u>Example of calculation</u> $E_k = 3.8 \times 10^{-16} \text{ J} = \frac{1}{2} 9.11 \times 10^{-31} \text{ kg} \times v^2$ $v = 2.90 \times 10^7 \text{ m s}^{-1}$	2
(b)(iii)	(Increasing the accelerating p.d.) would increase the (maximum) momentum of the electrons Or (Increasing the accelerating p.d.) would increase the (maximum) velocity of the electrons (1) Use of $\lambda = \frac{h}{p}$ so (de Broglie) wavelength of the electrons decreases (1) So the diameter of the circles would decrease Or Distance between maxima decreases (1)	3
Total for question		11

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	Electrons move to higher energy levels (1) They fall back to lower energy level (emitting a photon) (1)	allow atoms for electrons allow excited for moving to higher energy levels allow de-excited for fall back lower energy levels	2
(b)(i)	Calculates area of screen (1) Use of $I = \frac{P}{A}$ (1) Use of $P = \frac{W}{t}$ (1) $W = 131 \text{ (J)}$ (1)	<u>Example of calculation</u> $A = 7.15 \text{ cm} \times 14.7 \text{ cm} = 105 \text{ cm}^2$ $P = 50 \times 10^{-3} \text{ W cm}^{-2} \times 105 \text{ cm}^2$ $P = 5.25 \text{ W}$ $W = 5.25 \text{ W} \times 25 \text{ s}$ $W = 131.3 \text{ J}$	4

(b)(ii)	Use of $v = f\lambda$ with $v = 3 \times 10^8 \text{ ms}^{-1}$ (1) Use of $E = hf$ (1) divides total energy by energy of one photon (1) $N = 2.6 \times 10^{20}$ (photons) (1) (Allow ecf from (b)(i))	Example of calculation $f = \frac{3 \times 10^8 \text{ m s}^{-1}}{395 \times 10^{-9} \text{ m}} = 7.59 \times 10^{14} \text{ Hz}$ $E = 6.63 \times 10^{-34} \text{ J s} \times 7.59 \times 10^{14} \text{ Hz} = 5.03 \times 10^{-19} \text{ J}$ $N = \frac{131.25 \text{ J}}{5.03 \times 10^{-19} \text{ J}}$ $N = 2.61 \times 10^{20}$	4
(c)	EITHER (1) The energy levels in mercury atoms are fixed (1) So frequency of the uv light would stay the same OR (1) Electrons could move to higher energy levels (as the pd supplies more energy) (1) So frequency of the uv light would increase.	(MP2 dependent on MP1 being awarded) (MP2 dependent on MP1 being awarded)	2

(d)	Intensity (of the uv light incident on the screen) is increased (1) So the number of photons arriving per second is increased (1) Or So energy transferred per second to the glue is increased	Accept power increased	2
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