8	**The only correct answer is B** ***A*** *is not correct as the use of P and* $\frac{\lambda}{hc}$ *is incorrect.* ***C*** *is not correct as the use of P and* $\frac{\lambda}{hc}$ *is incorrect.* ***D*** *is not correct as the use of P and* $\frac{\lambda}{hc}$ *is incorrect.*	**(1)**

9	**B is the correct answer as the momentum of a photon is h/λ** A is not the correct answer as momentum is mv C is not the correct answer as it is not the speed of light, but the speed of the electron. D is not the correct answer as h is a constant.	**(1)**

9	**The only correct answer is C (The maximum kinetic of the photoelectrons energy depends on the frequency of the incident light.)** A is not correct as intensity only affects the number of photoelectrons released B is not correct because the frequency affects the kinetic energy of the photoelectrons D is not correct as the number of photoelectrons emitted per second depends on intensity	**1**

9	**A 6.63×10^{-34} the gradient of an $E_{k\,max}$ vs f graph is the Planck constant (as $E_{k\,max} = hf - \varphi$)**	**1**
	Incorrect answers: B this is the mass of an electron C this is the charge of an electron D this is the speed of light in a vacuum	

4	**C is the correct answer** A is not correct because attraction between opposite charges is not evidence of wave behaviour B is not correct because the electrons are behaving as particles D is not correct because the electrons are behaving as particles	**1**

6	**B is the correct answer** ($hf = \Phi + KE_{max}$ so increasing f increases KE_{max}) A is not the correct answer as electrons are released instantaneously C is not the correct answer as increasing intensity only increases the number of electrons released and each electron still has the same kinetic energy D is not the correct answer as it is higher frequency, not wavelength, that eventually passes a threshold value to release electrons	**(1)**
4	**A is the correct answer (de Broglie wavelength = 2.43 x 10^{-9} m)** B is not the correct answer as the de Broglie wavelength = 1.82 x 10^{-9} m C is not the correct answer as the de Broglie wavelength = 1.13 x 10^{-12} m D is not the correct answer as the de Broglie wavelength = 9.93 x 10^{-13} m	**(1)**

7	**B is the correct answer** A is not correct because the de Broglie wavelength would be 4λ. C is not correct because the de Broglie wavelength would be 0.5λ. D is not correct because the de Broglie wavelength would be 0.125λ.	1

4	**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)**

10	**B is the correct answer** A is not correct because gradient $= \frac{1}{hc}$ C is not correct because gradient $= \frac{1}{hc}$ D is not correct because gradient $= \frac{1}{hc}$	1

10	**The only correct answer is B ($h = \frac{1}{\text{c} \times \text{gradient}}$)** A is not correct because gradient $= \frac{1}{hc}$ C is not correct because gradient $= \frac{1}{hc}$ D is not correct because gradient $= \frac{1}{hc}$	1

3	**A is the correct answer** B is not correct because this would give the momentum of the electron C is not correct because this gives $\frac{1}{\text{velocity}}$ D is not correct because this would give $\frac{1}{\text{momentum}}$ for the electron	

5	**D is the correct answer as $v = \frac{h}{\lambda m}$** A is not the correct answer as v is not equal to $\frac{m}{h\lambda}$ B is not the correct answer as v is not equal to $\frac{\lambda m}{h}$ C is not the correct answer as v is not equal to $\frac{h\lambda}{m}$	**(1)**

4	**The only correct answer is B** $\left(\frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2 \times 10^{7}}\right)$ 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
5	$(25 \times 2\pi)$	1

6	**C is the correct answer** A is not correct because photoelectrons would have no kinetic energy at threshold frequency. B is not correct because this describes light emitted in an emission spectrum rather than light absorbed in the photoelectric effect. D is not correct because the frequency is not a maximum, and the electron should leave the surface rather than becoming excited.	**1**

18(a)	Electrons move to higher energy levels They fall back to lower energy level (emitting a photon)	**(1)** **(1)**	allow atoms for electrons allow excited for moving to higher energy levels allow de-excited for fall back lower energy levels	**2**

18(b)(i)	Calculates area of screen Use of $I = \frac{P}{A}$ Use of $P = \frac{W}{t}$ W = 131 (J)	**(1)** **(1)** **(1)** **(1)**	Example of calculation $A = 7.15\text{ cm} \times 14.7\text{ cm} = 105\text{ cm}^2$ $P = 50 \times 10^{-3}\text{ W cm}^{-2} \times 105\text{ cm}^2$ P = 5.25 W $W = 5.25\text{ W} \times 25\text{ s}$ W = 131.3 J	**4**

18(b)(ii)	Use of $v = f\lambda$ with $v = 3 \times 10^8\text{ ms}^{-1}$ Use of $E = hf$ divides total energy by energy of one photon $N = 2.6 \times 10^{20}$ (photons) (Allow ecf from (b)(i))	**(1)** **(1)** **(1)** **(1)**	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**

18(c)	**EITHER** The energy levels in mercury atoms are fixed So frequency of the uv light would stay the same **OR** Electrons could move to higher energy levels (as the pd supplies more energy) So frequency of the uv light would increase.	**(1)** **(1)** **(1)** **(1)**	(MP2 dependent on MP1 being awarded) (MP2 dependent on MP1 being awarded)	**2**

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

Question Number	Acceptable Answer		Additional Guidance	Mark
15(a)	**MAX 4**			
	Photons incident on (metal) surface / plate	**(1)**		
	Energy of one photon is transferred to one electron	**(1)**	Accept one photon interacts with one electron	
	Photon energy is proportional to frequency	**(1)**	Accept reference to $E = hf$	
	Some energy used to release the electron from the surface (of the metal) **Or** Some energy used to overcome the work function (of the metal)	**(1)**	Allow reference to threshold frequency being exceeded	
	Remaining energy transferred to kinetic energy of the electron (that are released)	**(1)**		**4**

15(b)(i)	Use of $v = f\lambda$	**(1)**	Example of calculation	
	Use of $E = hf$	**(1)**	$f = \frac{3.00 \times 10^{8}\ \text{m s}^{-1}}{380 \times 10^{-9}\ \text{m}} = 7.89 \times 10^{14}\ \text{Hz}$	
	$E = 5.2 \times 10^{-19}$ (J) (at least 2sf)	**(1)**	$E = 6.63 \times 10^{-34}\ \text{J s} \times 7.89 \times 10^{14}\ \text{Hz} = 5.23 \times 10^{-19}\ \text{J}$	**3**
15(b)(ii)	Conversion between J and eV	**(1)**	Example of calculation	
	Use of $hf = \Phi + \frac{1}{2}mv^2{}_{\text{max}}$	**(1)**	$5.23 \times 10^{-19}\ \text{J} \div 1.6 \times 10^{-19}\ \text{C} = 3.27\ \text{eV}$	
	Energy of electron = 1.1 (eV) (ecf from 15(b)(i)) (show that value gives 0.9 eV)	**(1)**	$3.27\ \text{eV} - 2.2\ \text{eV} = 1.07\ \text{eV}$	**3**
15(b)(iii)	Use of $I = \frac{P}{A}$	**(1)**	Example of calculation	
	Calculates $N = \frac{Pt}{E}$ with $t = 1$ s	**(1)**	$P = 8000\ \text{W m}^{-2} \times 0.02\ \text{m}^2 = 160\ \text{W}$	
	$N = 3.1 \times 10^{20}$ (ecf from 15(b)(i)) (show that value gives 3.2×10^{20})	**(1)**	$N = \frac{160\ \text{J} \times 1\ \text{s}}{5.23 \times 10^{-19}\ \text{J}} = 3.06 \times 10^{20}$	**3**
15(c)	Number of photons incident per second increases	**(1)**	If no other mark is awarded, award max 1 mark for statement of more photons gives more electrons so current increases.	
	Number of electrons released per second increases	**(1)**		
	Therefore current increases (MP3 dependent on MP1 or MP2)	**(1)**		**3**
	Total for question 15			**16**

Question Number	Answer		Mark
17(a)	Electron moves to a higher energy level Then drops back (down, releasing a photon) (MP1 allow electron is excited. MP2 allow electron is de-excited) (MP2 allow returns to ground state)	**(1)** **(1)**	**2**
17(b)(i)	Use of $v = f\lambda$ with $v = 3.00 \times 10^8$ m s^{-1} Use of $E = hf$ Conversion from J to eV Photon energy = 5.7 eV Example of calculation $v = f\lambda$, f = 3.00×10^8 m s^{-1} / 218×10^{-9} m = 1.38×10^{15} Hz $E = hf$ = 6.63×10^{-34} Js × 1.38×10^{15} Hz = 9.12×10^{-19} J E (in eV) = 9.12×10^{-19} J / 1.60×10^{-19} J eV^{-1} = 5.70 eV	**(1)** **(1)** **(1)** **(1)**	**4**
17(b)(ii)	(Differences between) energy levels are discrete **Or** only certain jumps/transitions are possible No difference of 5.7 eV, so not possible (for this photon to be produced) (MP2 – allow comment consistent with their calculated value from b(i))	**(1)** **(1)**	**2**
17(c)(i)	Use of $hf = \Phi + \frac{1}{2} mv^2_{max}$ Use of $E_k = \frac{1}{2} mv^2$ with $m = 9.11 \times 10^{-31}$ kg Maximum possible speed = 1.5×10^6 m s^{-1} Example of calculation $E_k = hf - \Phi = 1.63 \times 10^{-18}$ J – 5.89×10^{-19} J = 1.04×10^{-18} J $E_k = \frac{1}{2} mv^2$, $v = \sqrt{\frac{1.04 \times 10^{-18}\text{ J}}{0.5 \times 9.11 \times 10^{-31}\text{kg}}} = 1.5 \times 10^6$ m s^{-1}	**(1)** **(1)** **(1)**	**3**
17(c)(ii)	**MAX 2** from: • There is a minimum/threshold frequency for electron release • Electrons are released instantaneously • (Changing) intensity does not affect KE/speed/release of an electron **MAX 2** from: • The energy of a photon increases as frequency increases • Photon energy has to be greater than the work function • Each photon only interacts with one electron	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**3**
	Total for question 17		**14**

Question Number	Answer		Mark
17(a)	Use of $v = f\lambda$ Use of $E = hf$ Converts work function from eV to J Use of $hf = \Phi + \frac{1}{2} mv^2_{max}$ $v_{max} = 4.5 \times 10^6$ m s^{-1} (MP4 can only be awarded if values substituted are valid energy and mass values) Example of calculation $v = f\lambda$, 3.00×10^8 m s^{-1} = f × $(20 \times 10^{-9}$ m), f = 1.50×10^{16} Hz $E = hf$ = $(6.63 \times 10^{-34}$ Js) $(1.50 \times 10^{16}$ Hz) = 9.95×10^{-18} J Work function Φ = (3.68 eV) $(1.60 \times 10^{-19}$ J/eV) = 5.89×10^{-19} J $hf = \Phi + \frac{1}{2} mv^2_{max}$, 9.95×10^{-18} J = 5.89×10^{-19} J + $\frac{1}{2} mv^2_{max}$ $\frac{1}{2}$ $(9.11 \times 10^{-31}$ kg) $v^2_{max} = 9.36 \times 10^{-18}$ J $v_{max} = 4.53 \times 10^6$ m s^{-1}	(1) (1) (1) (1) (1)	5
17(b)	Increasing intensity leads to more photons/electrons But intensity does not affect the speed/ KE (of electrons) Increasing λ leads to a decrease in photon/light energy Leads to decrease in speed/ KE (for electrons), so student incorrect (MP1 – Allow equations with arrows correctly indicating increased and decreased components)	(1) (1) (1) (1)	4
	Total for Question 17		**9**

Question Number	Answer		Mark
19(a) (i)	Use of $E=hf$ (to find photon energy) $E = 1.3 \times 10^{-18}$ (J) The photon energy is greater than the work function So electrons (have sufficient energy to be) released (from the surface of the zinc) and the electroscope loses charge **OR** Use of $\emptyset = h f_0$ (to find threshold frequency) $f_0 = 1.0 \times 10^{15}$ (Hz) The frequency of the UV is greater than the threshold frequency So electrons (have sufficient energy to be) released (from the surface of the zinc) and the electroscope loses charge **OR** Use of KE = hf - $\emptyset$ (to find kinetic energy of electrons) KE = 6.4×10^{-19} (J) Kinetic energy value is positive So electrons (have sufficient energy to be) released (from the surface of the zinc) and the electroscope loses charge Example of Calculation $E = hf = 6.63 \times 10^{-34}$ J s $\times$ 2.0×10^{15} Hz $E = 1.3 \times 10^{-18}$ J	(1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	**4**
19(a)(ii)	One photon interacts with one electron (Same frequency so) photon/light/UV energy remains constant (At a lower intensity) there are fewer photons per second **Or** (at a lower intensity) there are fewer (photo)electrons per second So gold leaf's deflection would reduce more slowly **Or** so gold leaf takes more time to fall	(1) (1) (1) (1)	**4**

19(b)	**Max 3 from** Electrons are released instantaneously (even at low intensity) **Or** in the wave model electrons would be released after a delay	(1)	
	There is a minimum frequency for releasing electrons **Or** in the wave model electrons are released at any frequency	(1)	
	More intense light does not increase (kinetic) energy of electrons **Or** in the wave model more intense light increases (kinetic) energy of electrons	(1)	
	There is a maximum kinetic energy of electrons for a specific frequency **Or** in the wave model there is no maximum kinetic energy of electrons for a specific frequency	(1)	**3**
	Total for question 19		**11**