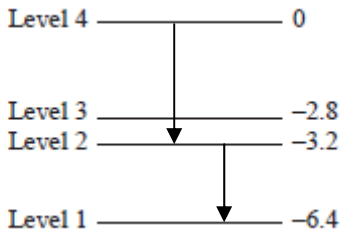
Question Number	Answer	Mark
1*(a)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) With waves energy could build up **(1)** Any ke could be possible **Or** ke would not be limited **(1)** One photon to one electron **(1)** $E = hf$, so energy transfer limited **Or** $\frac{1}{2} mv^2 = hf - \varphi$ so there is a maximum ke **(1)**	**4**
(b)	Use of $E = hf$ **(1)** Correct use of 1.6×10^{-19} C **(1)** Use max ke = $hf - \varphi$ **(1)** $\frac{1}{2} mv^2 = 1.3 \times 10^{-18}$ J **(1)** <u>Example of calculation</u> $E = 6.63 \times 10^{-34}$ J s $\times$ 2.5×10^{15} Hz $= 1.7 \times 10^{-18}$ J $\varphi = (2.3 \text{ eV} \times 1.6 \times 10^{-19} \text{ C})$ J $= 3.7 \times 10^{-19}$ J $\frac{1}{2} mv^2 = 1.7 \times 10^{-18}$ J $- 3.7 \times 10^{-19}$ J $= 1.3 \times 10^{-18}$ J	**4**
	Total for Question	**8**

Question Number	Answer		Mark
2(a)	Packet / package / quantum of …(energy / light / e-m radiation / light energy / e-m energy – something relevant – no mark simply for packet …) … <u>electromagnetic</u> radiation / <u>electromagnetic</u> energy (independent mark)	**(1)** **(1)**	**2**
(b)(i)	An allowed/possible/specific/discrete quantity of energy for (an electron in) the atom	**(1)**	**1**
(b)(ii)	(Photon is emitted when) an electron moves to a lower energy level The lowest frequency photon will be emitted for a transition from level 5 to level 4 Use of difference in energy levels in eV Use of $W = QV$ for conversion to Joule Use of $E = hf$ Frequency = 4.1×10^{13} Hz <u>Example of calculation</u> difference in energy levels = $(-0.38 \text{ eV}) - (-0.55 \text{ eV}) = 0.17$ eV $W = 0.17 \times 1.6 \times 10^{-19}$ J $f = 0.17 \times 1.6 \times 10^{-19}$ J $\div$ 6.63×10^{-34} J s $= 4.1 \times 10^{13}$ Hz	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**6**
	Total for Question		**9**

Question Number	Answer		Mark
***3**	**(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)** • Photons (from incident light) • Photons/light/e-m radiation cause emission of electrons from surface of metal • Photon has energy hf ($E = hf$ not sufficient alone, but link of E to photon may follow on by implication from previous writing) • Emission only if photon energy greater than (or equal to) φ (work function) **Or** φ (work function) is minimum energy required for emission of electrons • $\frac{1}{2} mv^2$ is the kinetic energy of the emitted electron • (It is max because) some energy may be transferred to the metal (accept description of more energy required to reach surface if atom/electron not at the surface)	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**6**
	Total for Question		**6**

Question Number	Answer		Mark
4(a)	The (minimum) energy required to remove one/an electron from the surface of the metal (must refer to surface)	**(1)**	**1**
***4(b)**	(QWC- Work must be clear and organised in a logical manner using technical wording where appropriate.) • Increasing the intensity (of light) increases the number of electrons emitted(per sec) **Or** number of electrons emitted(per sec) depends on the intensity (of light) • One photon releases one electron • Intensity determines number of photons **OR** • Increasing the intensity (of light) does not increase the energy/speed of the electrons • One photon releases one electron • Energy of photon determined by/depends on frequency (not intensity) **Or** $E = hf$ **OR** • Below a certain frequency / threshold frequency no electrons emitted **Or** above a certain wavelength no electrons emitted • Energy of photons increases with / depends on frequency **Or** $E = hf$ • Each photon needs a minimum amount of energy / work function **Or** One photon releases one electron **OR** • Electron emission starts at once (even for low intensity) • One photon releases one electron • Wave theory would allow energy to build up **OR** • Increasing the frequency (of light) increases the energy/speed of the electrons **Or** Increasing the frequency (of light) increases the stopping potential • Energy of photon determined by/depends on frequency **Or** $E = hf$ • One photon releases one electron **Or** Wave theory would allow energy to build up (Max one mark for a 2nd or 3rd point if no correct observation given)	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**3**
	Total for question		**4**

Question Number	Answer		Mark
5(a)	A statement which implies only certain energy levels are allowed e.g. Allowed/possible energy of atoms/electrons Discrete energy of an atom/electron	**(1)**	**1**
5(b)	Identifies correct pairs of levels, 4 and 2 **AND** levels 2 and 1 Two arrows both showing correct direction [irrespective of identified levels]  	**(1)** **(1)**	**2**
5(c)	**Max 3** Atom/electron gains energy and moves to a higher level **Or** atom/electron becomes excited atom/electron has discrete energies **Or** atom/electron can only move between fixed levels **Or** only certain energy changes are possible atom/electron falls to a lower level By emitting energy in the form of photons **Or** reducing their energy by emitting photons Photons have a specific energy/frequency **Or** reference to $E = hf$ **Or** photon energy $= E_2 - E_1$	**(1)** **(1)** **(1)** **(1)** **(1)**	**3**
5(d)	Use of $E = hf$ with any of the possible energy differences Identifies ΔE as (±) 0.4 ($\times 10^{-19}$ J) $f = 6.0 \times 10^{13}$ Hz <u>Example of calculation</u> Smallest energy difference is 0.4×10^{-19} J $f = 0.4 \times 10^{-19}$ J / 6.63×10^{-34} Js $f = 6.03 \times 10^{13}$ Hz	**(1)** **(1)** **(1)**	**3**
5(e)	Divides an energy by 1.6×10^{-19} Energy = 4.0 (eV) (no ue) <u>Example of calculation</u> Energy = 6.4×10^{-19} J /1.6×10^{-19} C Energy = 4.0 eV	**(1)** **(1)**	**2**
	Total for question		**11**

Question Number	Answer	Mark
6 (a)	A statement which implies only certain energies are allowed e.g. Allowed/possible energy of atom/electron (in an atom) Discrete energy of an atom/electron One of the energies of the atom/electron Energy an atom/electron can have	**1**
(b)	Photon is a (discrete) package/packet/quantum of (electromagnetic) energy/particle of light	**1**
(c)	(energy of) E_2 – (energy of)E_1	**1**
(d)	See $E = h c / \lambda$ **OR** use of $v = f\lambda$ Substitution into $E = h c / \lambda$ **OR** use of $E = hf$ $E = 3.14 \times 10^{-19}$ J or 1.96 eV **Example of answer** $E = (6.63 \times 10^{-34}$ Js × 3× $10^{8}) \div 6.33 \times 10^{-7}$ m $E = 3.14 \times 10^{-19}$ J	**1** **1** **1**
	Total for question	**6**

Question Number	Answer	Mark
7	Addition of words (order essential) photon metal energy (allow mass, charge, momentum) (photo)electron work function (of the metal)	 **1** **1** **1** **1** **1**
	Total for question	**5**

Question Number	Answer	Mark
8(a)	Photon energy is too small / less than work function (**do not** credit the frequency is less than the threshold frequency or electrons have not been given enough energy)	**(1)**
8(b)	**Method 1: Use of intercept x-axis** Use of $E = hf$ with $f = 10 \times 10^{14}$ Hz Divide by 1.6×10^{-19} to convert to eV (this mark can be scored even if wrong frequency used) $\Phi = 4.1$ (eV) Unit given on paper so no ue and ignore reference to J **OR** **Method 2:Use of Photoelectric Equation** Use of $hf = \Phi + E_{max}$ with any pair of values Divide by 1.6×10^{-19} to convert to eV $\Phi = 4.1 - 4.5$ (eV) Unit given on paper so no ue and ignore reference to J	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(max 3)**
8(c)	Gradient of graph is Planck's constant/e (accept just Planck's constant)	**(1)**
8(d)	Graph parallel to original graph cutting X axis with a value less than 10	**(1)** **(1)**
	Total for question	**7**