Question Number	Answer	Mark
***2 (a)**	**(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)** Only one photon can transfer energy to a single electron **Or** a photon transfers all of its energy to a single electron **(1)** Photon energy depends on frequency **Or** photon energy = hf **(1)** Therefore photons must have a frequency greater than or equal to the minimum frequency (threshold frequency) in order to provide sufficient energy **Or** photon energy must be greater than work function **(1)** Light with a greater intensity supplies more photons per second **(1)** So more electrons can be emitted per second, causing a greater current **(1)** MP4 and MP5 can both be awarded if 'per second' mentioned at least once.	**5**
2 (b)	Use of $E = hf$ **(1)** Use of energy divided by 1.6×10^{-19} C **(1)** Maximum electron ke = 0.49 (eV) **(1)** <u>Example of calculation</u> Max ke = 6.63×10^{-34} Js × (7.52×10^{14} Hz - 6.34×10^{14} Hz) ÷ 1.6×10^{-19} C = 0.49 eV	**3**
	Total for question	**8**

Question Number	Answer	Mark
3(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**
3(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**

Question Number	Answer		Mark
4(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)		
4(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**

Question Number	Answer		Mark
5(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**
5(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		
5(c)	From kinetic energy of atoms	**(1)**	**1**
5(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**

Question Number	Answer		Mark
6(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**
***6(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		
6(c)(i)	Use of $4.3 \times 1.6 \times 10^{-19}$	**(1)**	
		(1)	
	Use of $E = hf$	**(1)**	**3**
	$f = 1.0 \times 10^{15}$ Hz		
	<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		
6(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)**	
	Total for question		**11**

Question Number	Answer	Mark
7(a)(i)	**Effect**: (Max) (K)E/speed/velocity (of electrons) increases (accept electrons move faster) **(1)** **Explanation**: (Increasing frequency) increases energy of <u>photon</u> **(1)** If there is reference to both energy and number of electrons increasing, do not award the first mark.	**2**
7(a)(ii)	**Effect**: Number (of electrons)/sec emitted increases / rate of (electron) emission increases (accept reference to increased current) **(1)** **Explanation**: There are more photons/sec **(1)** Either mark may be awarded without reference to '/sec' or rate, but only award 2 marks for the rate effect and explanation if there is reference to rate or '/sec' at least once If there is reference to both energy and number of electrons increasing, do not award the first mark.	**2**

7(b)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Observation from photoelectric effect (max 1 mark)** • No of electrons emitted depends on intensity / doesn't depend on frequency • Emission of electrons is instantaneous / no time delay • Minimum frequency for electron emission (i.e. reference to threshold frequency, not work function) • (Max) electron (kinetic) energy depends on frequency / doesn't depend on intensity (accept reference to stopping potential) **Explanation (max 3 marks):** **Particle nature** Reference to $E=hf$ or quanta of energy / packets of energy / photons **Use to explain observation** One photon releases one electron **Or** Electron release requires minimum energy / work function energy **Or** (Max) Electron energy is photon energy – work function energy **Or** $\frac{1}{2} mv^2 = hf - \varphi$ **Wave nature** Wave energy depends on intensity **Or** Energy spread over whole wave **Or** Energy supply is continuous (accept energy can build up) **Use to explain observation** So more intense light should give greater (K)E (which it doesn't) **Or** If given enough time electrons eventually released (which doesn't happen) **Or** a delay could be expected before electron release (which doesn't happen)	**(1)** **(1)** **(1)** **(1)** **(1)**	**4**
	Total for question		**8**

Question Number	Answer		Mark
8(a)	(Atoms/electrons) gain energy	**(1)**	
	(Electrons/atoms) move to higher energy levels/states **OR** level/state above ground state	**(1)**	**2**
	'electron shells' not sufficient		
8(b)(i)	Electrons/atoms move to lower energy level/state (accept ground state) **Or** Electrons/atoms moves down from a higher energy level/state	**(1)**	
	Emit photons **Or** emit quanta/packets of electromagnetic radiation (emit radiation not sufficient)	**(1)**	**2**
8(b)(ii)	Atoms/electrons exist in certain/discrete/specific energy (levels) (do not allow 'fixed')	**(1)**	
	Only certain energy changes are possible **Or** Only certain/discrete/ fixed amounts of energy are released (accept reference to 'amounts of eV' for energy)	**(1)**	
	Refer to $E = hf$	**(1)**	**3**
8(b)(iii)	(Phosphor) has different energy level (spacing)s **Or** different elements have different energy level (spacing)s (Not shells, not different number, not configuration)	**(1)**	**1**
	Total for question		**8**

Question Number	Answer		Mark
9(a)(i)	Use of v = fλ with v = 3.00 x 10^8 (ms^{-1})	**(1)**	
	f = 4.57 × 10^{14} Hz (allow s^{-1})	**(1)**	**2**
	<u>example of calculation</u> f = $\frac{3 \times 10^8 \text{ m s}^{-1}}{6.56 \times 10^{-7} \text{ m}}$ f = 4.57 × 10^{14} Hz		
9(a)(ii)	Correct use of 1(eV) = 1.6 × 10^{-19}(J) to convert eV to J or J to eV e.g. $\frac{3.03 \times 10^{-19}}{1.6 \times 10^{-19}}$ = 1.9 (eV)	**(1)**	
	Transition **from** (-)1.5 (eV) **to** (-)3.4 (eV)	**(1)**	**2**
9(b)	Wavelength increased or stretched /frequency decreased/red shift/ Doppler effect	**(1)**	
	Galaxy is moving away (from us/sun)	**(1)**	**2**
	Total for question		**6**