1)

(a)	(i)	photoelectric effect (experiment) **or** (discrete) counting of gamma rays **or** Compton effect	B1	**NOT** the gold leaf/ the zinc plate experiment, etc.
	(ii)	Young's slits (experiment)	B1	**accept** any interference/diffraction experiment, e.g. using a diffraction grating, a double slit experiment, etc.
(b)	(i)	φ is the minimum energy required to release an electron from the metal/surface	B1	**allow** escape from
	(ii)	$KE_{max} = hf - \varphi$ or $hf = \varphi + KE_{max}$ **the straight line equation is y = mx + c (where m is the gradient and c the y-intercept)** hence giving c = (-) φ and m = h	B1 **M1** A1	can be copied from the data sheet
	(iii)1	**h = 32 x 10^{-20}/5 x 10^{14} or 40 x 10^{-20}/6.25 x 10^{14} or 20 x 10^{-20}/3 x 10^{14} etc** = 6.4 x 10^{-34} (J s)	**M1** A1	any sensible attempt at gradient gains 1 mark check that answer is consistent with figures and not just quoted, e.g. 6.7 for third set of data above
	(iii)2	8.75 ± 0.25 x 10^{14} (Hz)	B1	tolerance is to within the grid square **N.B.** SF applies i.e answer must be 9.0 NOT 9
	(iii)3	φ = 6.4 x 10^{-34} x 8.75 x 10^{14} = 5.6 x 10^{-19} (J)	C1 A1	**ecf (b)(iii)1,2 or ecf b(iii) 2** x 6.6(3) x 10^{-34} ans = **1** x **2**; 5.8 x 10^{-19} (J) if use h = 6.6 x 10^{-34} **allow** use of $\varphi = hf - KE_{max}$ at (15,40) for example
		Total	**11**	

2)

a	**i**	photoelectric effect/emission	B1	
	ii1	the minimum energy (required) to release an electron (from the surface of the metal)	B1	
	ii2	3.5 x 10^{-19} = 6.6 x 10^{-34} f f = 5.3 x 10^{14} (Hz)	C1 A1	
	iii	ε = hc/λ = 6.6 x 10^{-34} x 3.0 x 10^{8}/ 4.2 x 10^{-7} = 4.7 x 10^{-19} (J)	C1 A1	no second mark unless there is evidence of the calculation being done
	iv	½mv² = 4.7 x 10^{-19} – 3.5 x 10^{-19} = 1.2 x 10^{-19} (J)	C1 A1	mark for using the p.e. equation **accept** 1.5 x 10^{-19} from those using 5 x 10^{-19} J
b	**i1**	12 (eV)	B1	
	ii2	ε = eV = 12 x 1.6 x 10^{-19} =1.92 x 10^{-18} (J)	A1	**ecf(b)(i)1**
	ii	½mv² = 2.0x 10^{-18} v² = 2 x 2.0 x 10^{-18}/9.1 x 10^{-31} = 4.4 x 10^{12} v = 2.1 x 10^{6} (m s^{-1})	C1 C1 A1	½mv² = 12 scores 0/3 **accept** 1.9 x 10^{-18} from **(b)(i)2** giving v = 2.0(5) x 10^{6}
c		e's emitted/s = 1.2 x 10^{-8}/5 x 10^{-19} = 2.4 x 10^{10} current = 2.4 x 10^{10} x 1.6 x 10^{-19} = 3.8 x 10^{-9} (A) to 4.1 x 10^{-9} (A)	C1 C1 A1	using 4.7 x 10^{-19} gives 2.55 x 10^{10} omitting 1% scores as a POT error allow 4 nA as the question states 'estimate'
		Total question 4	**16**	

3)

(a)	**(i)**	emission of electron(s) from a <u>metal</u> (surface) when photon(s)/ light/uv/em radiation are incident (on surface)	B1	**allow** singular electron and absorption of photon
	(ii)	energy to accelerate/move an electron through a p.d. of 1 V/AW	B1	**not** 1.6×10^{-19} J
	(iii)	$5.0 \times 1.6 \times 10^{-19} = 8.0 \times 10^{-19}$ J	B1	**allow** 8 for 8.0; no mark if unit incorrect
(b)	**(i)1**	the <u>minimum</u> energy required to release an electron from the <u>surface</u> of the metal	B1	
	(i)2	$\varphi = 8.0 \times 10^{-19} - 1.1 \times 10^{-19}$ $= 6.9 \times 10^{-19}$ J	B1	no mark if unit incorrect unless unit in **a(iii)** incorrect
	(ii)1	$\frac{1}{2}mv^2 = 1.1 \times 10^{-19}$ $v^2 = 2.2 \times 10^{-19}/9.11 \times 10^{-31}$ $(= 2.4 \times 10^{11})$ $v = 4.9 \times 10^5$ (m s^{-1})	C1 M1 A0	**accept ora** substitute 5×10^5 to find $E = 1.1 \times 10^{-19}$
	(ii)2	$\lambda = h/mv$ $= 6.63 \times 10^{-34} / 9.11 \times 10^{-31} \times 4.9 \times 10^5$ $= 1.5 \times 10^{-9}$ (m)	C1 C1 A1	**accept** 1.46×10^{-9} if using $v = 5 \times 10^5$
(c)	**(i)**	Electrons behave as waves/diffract (observable because) gaps/atoms are of similar wavelength to electrons <u>regular/ordered</u> pattern of atoms/atoms act as a grating/AW allowing interference to produce pattern on screen/AW rings occur because atomic 'crystals' at all possible orientations to beam/AW	B1 B1 B1 B1 B1	**allow** graphite for atoms **max** 3 from 5 marking points
	(ii)	wavelength is too large to produce a diffraction pattern/electrons not travelling fast enough/AW	B1	**ecf (b)(ii)2**; e.g. for AW: wavelength is about 10 times atomic spacing **or** wavelength is different to spacing
		Total	**14**	

4)

a	**i**	energy φ required for an electron to escape from <u>metal surface</u> the minimum energy.....	**M1** **A1**	inclusion of the word minimum in the sentence scores the second mark
	ii	a <u>photon</u> with less than the threshold frequency f_0 cannot cause electron emission/AW so work function = h (threshold frequency)	**B1** **B1**	**allow** $\varphi = hf_0$ when the symbols φ and f_0 have been defined somewhere in the question
	iii	$\varphi = hc/\lambda$ $= 6.63 \times 10^{-34} \times 3.0 \times 10^8/550 \times 10^{-9}$ $= 3.6 \times 10^{-19}$ (J)	**C1** **A1**	
b	**i**	$KE_{max} = hf - \varphi$ or $hf = \varphi + KE_{max}$ $hf = 6.63 \times 10^{-34} \times 3.0 \times 10^8/440 \times 10^{-9} = 4.5 \times 10^{-19}$ J $\frac{1}{2}mv^2 = 9 \times 10^{-20}$ giving $v^2 = 1.8 \times 10^{-19}/9.1 \times 10^{-31}$ $v = 4.45 \times 10^5$ (m s^{-1})	**C1** **B1** **B1** **A0**	**ecf (a)(iii)** allow 4.5 or 4.4×10^5
	ii	$\lambda = h/mv = 6.63 \times 10^{-34}/9.1 \times 10^{-31} \times 4.5 \times 10^5$ $\lambda = 1.6 \times 10^{-9}$ (m)	**C1** **A1**	allow 1.7×10^{-9} for $v = 4.4 \times 10^5$
c	**i**	n = 3 <u>to</u> n = 2	**B1**	**allow** between **or** and **when** there is a downward arrow on Fig. 8.1
	ii	$E_{32} + E_{21} = E_{31}$ $hc/\lambda_{32} + hc/\lambda_{21} = hc/\lambda_{31}$ $1/590 + 1/440 = 1/252$ so $\lambda_{31} = 250 \times 10^{-9}$ (m)	**C1** **C1** **A1**	**accept** equation using $1/\lambda$ **or** $1/590 + 1/440 = 1/\lambda_{31}$ **allow** 2 or 3 sf **allow** 2/3 for using 550 for 590 nm giving 244 nm
		Total	**15**	

5)

a		photoelectric effect	B1	
b		**1.**Individual photons are absorbed by individual electrons (in the metal surface)/ one to one interaction/AW **2.**Only photon with energy above the work function energy will cause photoelectron emission/idea of threshold frequency **3.**Photon energy is proportional to frequency **4.**(therefore) blue photons with higher f/shorter λ will cause photoemission but red photons will not. **5.**$hf - \phi = KE_{max}$ is the equation resulting from conservation of energy **or** resulting from the meaning of each term **6.**A wave model does not explain instantaneous emission	B1 B1 B1 B1 B1	**max** 4 from 6 marking points **allow** work function (of a metal surface) is minimum energy for photoemission **allow** shorter wavelength light has higher energy (hc/ λ) or higher frequency higher energy (hf) **or** ….red photons with lower f/longer λ….. *max* must be present to score mark; equation stated in words: photon e. – w.f. = max ke of *e* to score full marks (4) the answer **must include** two terms out of *photon, work function* and *threshold frequency/wavelength* (QWC mark)
c	**i**	work function = $\phi = hc/\lambda$ $\varphi = 6.6 \times 10^{-34} \times 3.0 \times 10^{8} / 4.8 \times 10^{-7}$ $= 4.1(4) \times 10^{-19}$ (J)	C1 M1 A1	allow $\phi = hf$ ($f = 6.25 \times 10^{14}$) and $f = c/\lambda$ must show answer initially to 2 or 3 SF; ignore any final rounding down to 1 SF
	ii	$E - \phi = ½ mv^2$ $(5.2 - 4.1) \times 10^{-19} = 1.1 \times 10^{-19} = ½ mv^2$ $v = \sqrt{(2 \times 1.1 \times 10^{-19} / 9.1 \times 10^{-31})}$ $v = 4.9 \times 10^{5}$ (m s^{-1})	C1 C1 A1	can use 4.14 or 4 instead of 4.1 **allow** 5.1×10^{5} (m s^{-1}) using $\phi = 4 \times 10^{-19}$ or 4.8×10^{5} (m s^{-1}) using $\phi = 4.14 \times 10^{-19}$
d	**i**	electrons passing through a thin sheet of graphite are diffracted/produce diffraction rings on a fluorescent screen	M1 A1	any suitable/reasonably plausible situation what is observed/ interpretation
	ii	$\lambda = h/mv$ $\lambda = 6.63 \times 10^{-34} / 5.0 \times 10^{5} \times 9.1 \times 10^{-31}$ $\lambda = 1.5 \times 10^{-9}$ (m)	C1 C1 A1	 1.46 to 3 SF
		Total question 6	**16**	

6)

a photon is absorbed by an electron (in a metal surface); causing electron to be emitted (from surface). Energy is conserved (in the interaction).	B1 B1 B1	**not** hits QWC mark
Only photons with energy/frequency above the work function energy/threshold frequency will cause emission Reference to Einstein's photoelectric energy equation (energy of photon) = (work function of metal) + (maximum possible kinetic energy of emitted electron) work function energy is the minimum energy to release an electron from the surface Number of electrons emitted also depends on light intensity Emission is instantaneous	B1 B2 B1 B1 B1	3 marks from 6 marking points in symbols only scores 1 mark out of 2, i.e. selects from formula sheet

7)

Question			Expected Answers	Marks	Additional Guidance
7	a		A (clean) zinc plate mounted on the cap of a gold-leaf electroscope. Plate initially charged negatively A u-v lamp shining on plate The gold leaf collapses as the charge leaks away from the plate (when ultra-violet light is incident on the zinc plate) so experiment indicates the emission of negative charge/electrons	B1 B1 B1 B1 B1	first 3 marks can be awarded from diagram or description QWC mark
		Or	A simple photocell, eg two plates in a vacuum envelope A (12 V) dc supply is connected to the photocell and (nano)ammeter. A suitable frequency/u-v lamp shining on one plate The presence of u-v /blue light causes a current in the circuit. so experiment indicates the emission of negative charge/electrons	B1 B1 B1 B1 B1	**accept** photocell made of clean magnesium ribbon surrounded by fine copper gauze first 3 marks can be awarded from diagram or description **ignore** polarity of supply QWC mark
		Or	A (potassium) photocell connected across a (high impedance) voltmeter. Incident light of different frequencies; produced either by white light source and colour filters of known spectral range or by using a diffraction grating or prism to produce a first order spectrum. Different p.d.s are set up across the electrodes of the photocell (when the photocathode is illuminated with light of different frequencies). so experiment indicates the emission of negative charge	B1 B1 B1 B1 B1	first 3 marks can be awarded from diagram or description QWC mark
	b		Individual photons are absorbed by individual electrons in the metal surface. These electrons must have absorbed sufficient energy to overcome the work function energy of the metal/to reach the minimum energy to release an electron from the surface **or** only photons with energies above the work function energy will cause photoelectron emission Concept of instantaneous emission Number of electrons emitted also depends on light intensity Einstein's photoelectric energy equation in symbols with symbols explained, ie (energy of photon) = (work function of metal) + (maximum possible kinetic energy of emitted electron)	 B1 B1 B1 B1 B1 B1	**stop marking after the first five marking points, ie ticks and crosses** **not** photons are absorbed by electrons; 1 to 1 relationship must be implied **accept** definition of work function energy **accept** shorter λ/higher f photon causes higher (kinetic) energy electron **accept** full word equation without symbols for 2 marks maximum 5 marks
			Total question 7	**10**	