1)

Question			Expected Answers	M	Additional Guidance
	a		an eV is the energy acquired by an electron accelerated/moves through a p.d. of 1 V 1 eV = 1.6 x 10^{-19} J	B1 B1	
	b	i	300 (eV) 4.8 x 10^{-17} (J)	B1 B1	1 mark if write correct answers on wrong lines **ecf** for (first answer) x 1.6 x 10^{-19} e.g. 7.68 x 10^{-36} using 4.8 x 10^{-17}
		ii	½mv^2 = 4.8 x 10^{-17} ⇨ v^2 = 9.6 x 10^{-17}/ 9.1 x 10^{-31} (= 1.06 x 10^{14}) v = 1.03 x 10^7 (m s^{-1})	M1 A1	**allow** 1 mark only for v^2 = 2 x **b(i)**/ 9.1 x 10^{-31} if **b(i)** incorrect **allow** 1.0 x 10^7, 1 x 10^7 is not acceptable
	c	i	Electrons are observed to behave as waves/show wavelike properties where the electron wavelength depends on its speed/momentum	B1 B1	**accept** by being diffracted (by a crystal lattice)/AW **accept** de Broglie eqn with m,v or p defined
		ii	λ = h/mv = 6.63 x 10^{-34}/(9.1 x 10^{-31} x 1.03 x 10^7) = 7.1 x 10^{-11} (m)	C1 A1	**allow** 1 mark for 3.9 or 4.0 x 10^{-14} (m) caused by subs m_p for m **allow** 7.3 x 10^{-11} (m)
			Total question 6	**10**	

2)

a	**i**	vertical arrow upwards from ground state to zero level or above	B1	
	ii	21.8 x 10^{-19} (J)	B1	**no ecf** from (i); ignore sign
b	**i**	E = hc/ λ = 6.63 x 10^{-34} x 3.0 x 10^8/4.9 x 10^{-7} = 4.06 x 10^{-19} (J) **or** 4.1 x 10^{-19} (J)	M1 A1	**accept** use of 6.6 instead of 6.63 which can round down answer to 4.0(4)
	ii	vertical arrow downwards between n = 4 to n = 2 levels	B1	
c		some photons will be absorbed hydrogen atoms become excited (excited) hydrogen atoms re-emit photons the photon energy is equal to the transition n = 1 to n = 3	B1 B1 B1 B2	**not** hits **allow** electron moves up energy levels **NB** full marks = lines 1 + 4 or 1 + 2 + 3
		Total question 8	**8**	

3)

Question			Expected Answers	Marks	Additional Guidance
	a	i	E = hc/λ = 6.63 x 10^{-34} x 3.0 x 10^8/ 6.3 x 10^{-7} = 3.16 x 10^{-19} (J)	M1 A1	mark is for correct substitution into formula min of 2 sig figs;**allow** 3.1 for h = 6.6 x 10^{-34}
		ii	1.0 x 10^{-3}/3(.2) x 10^{-19} (= 3.1 x 10^{15})	B1	**accept** 3 x 10^{15}; the mark is for the expression
		iii	energy levels explanation: electrons have discrete energies in atom/AW each photon produced by electron moving between levels photon energy equal to energy difference between levels electron loses energy/making transition in correct direction	B1 B1 B1 B1	QWC mark good diagram can score marks **allow** $E_1 - E_2$ = hf or similar
		iv	blue light has a higher frequency/shorter wavelength than red light energy per photon is higher (so fewer needed to produce one mW)	B1 B1	
	b	i	vertical arrow up approximately through **X**	B1	**allow** tolerance e.g. ± 10°
		ii	I = 0.2 ne ; = 0.2 x 3.2 x 10^{15} x 1.6 x 10^{-19} = 1.0(24) x 10^{-4} (A) or 0.10 mA (9.6 x 10^{-5} if using 3 x 10^{15})	C2 A1	**max** 2 marks if forget 0.2 factor 0.51 mA (0.48) if forget 0.2 factor
		iii	reflection/absorption at top layer; light/some photons reach bottom layer; photons below threshold energy/photons absorbed by electrons without release; recombination of ion pairs in insulating layer; scattering of light/photons out of insulating layer	B1	**award** mark for any sensible comment; see examples given
			Total question 7	**14**	

4)

a	**i**	paths spread out after passing through a gap or around an obstacle/AW	B1	
	ii	wavelength of electrons must be comparable/of the order of magnitude of the atomic spacing	M1 A1	**allow** electrons behave as waves/AW **allow** must be about 10^{-10} m
b		$\lambda = h/mv$ $v = 6.6(3) \times 10^{-34} / 9.1(1) \times 10^{-31} \times 1.2 \times 10^{-10}$ $= 6.0$ or 6.1×10^{6} (m s^{-1})	C1 M1 A1	mark for selecting formula correct manipulation and subs. shown **give** all 3 marks for answers to 3 figs or more: i.e. 6.04, 6.06 or 6.07
c	**i**	$eV = \frac{1}{2}mv^2$ $V = mv^2/2e = 9.1 \times 10^{-31} \times (6.0 \times 10^{6})^2/2 \times 1.6 \times 10^{-19}$ $= 1.0(2) \times 10^{2}$ (V)	C1 C1 A1	mark for algebraic equation mark for correct substitution **give** 1 mark max for k.e. = $1.6(4) \times 10^{-17}$ J using 6.1 gives 104 (V)
	ii	electrons should be repelled by cathode and/or attracted by anode **or** they will be attracted back to the cathode/slowed down if cathode positive	B1	**award** mark if answer indicates this idea
		Total question 8	**10**	

5)

select $E = hc/\lambda$ $E = 6.63 \times 10^{-34} \times 3.0 \times 10^{8}/436 \times 10^{-9}$ $E = 4.56 \times 10^{-19}$ (J)	C1 C1 A1	**do not allow** 4.6×10^{-19} unless SF mark already deducted
1 arrow correctly labelled 2 more arrows correctly labelled	B1 B1	

6)

(a)		the energy of an electron✓ equals the energy of the (emitted) photon✓	B1 B1	**alt:** the electron energy✓ is converted into the energy of the emitted photon✓ **or** the minimum energy✓ of an electron required to produce a photon✓/AW
(b)		Adjust the potential divider to low/zero voltage connect flying lead to one LED increase voltage until LED just lights/strikes repeat several times and average to find V_{min} repeat for each LED shield LED inside opaque tube to judge strike more accurately	B1 B1 B1 B1 B1 B1	**max** 3 marks
(c)	**(i)**	values of $1/\lambda$ calculated correctly: 2.14 and 2.43 2 points plotted correctly line of best fit drawn through origin gradient = 1.24×10^{-6} (V m)	B1 B1 B1 B1	**not** 2.13 unless this is second rounding error in paper **ecf** calculated values in table working **must be shown** to score the mark **allow ecf** for correct gradient from line drawn
	(ii)	gradient of line = $V\lambda$ from $eV = hc/\lambda$ $\quad V\lambda = hc/e$	B1 B1	**must have** clear indication that $V\lambda$ is gradient of graph
	(iii)	$1.24 \times 10^{-6} = hc/e$ $h = 1.24 \times 10^{-6} \times 1.6 \times 10^{-19} / 3.0 \times 10^{8}$ $h = 6.6(1) \times 10^{-34}$ (J s)	 M1 A1	**ecf (c)(i)** correct substitution into equation mark ans = 5.3 x grad (ignoring all powers of 10)
		Total	**13**	

7)

Question			Expected Answers	M	Additional Guidance
7					
	a	i	light emitted from (excited isolated) atoms produces a line spectrum a series of (sharp/bright/coloured) lines against a dark background	B1 B1	**max 2 marks** from 3 marking points
		ii	in an absorption spectrum a series of dark lines (appears against a bright background/within a continuous spectrum)	B1	**accept** black
	b	i	$\varepsilon = hc/\lambda$ $= 6.63 \times 10^{-34} \times 3.00 \times 10^{8} / 436 \times 10^{-9}$ $= 4.56 \times 10^{-19}$ (J)	C1 C1 A1	**apply** SF error if all numbers not to 3+ figures 4.54 if use 6.6
		ii	3.64×10^{-19} (J)	A1	**allow** mark if repeated error from **b(i)**
	c	i	correct vertical lines; correct labels arrow(s) downwards	B1 B1 B1	**1 mark** for 1 vertical line + correct label
		ii	$-8.86 + 4.56 = -4.3 \times 10^{-19}$ (J) $-7.94 + 3.64 = -4.3 \times 10^{-19}$ (J)	B1 B1	**ecf b(i)** **do** calculation for one line only correctly scores 2 marks; give answer as 4.3×10^{-19} **or** -4.3 scores 1 mark **do** calculation for both lines and give answer as 4.3×10^{-19} **or** -4.3 scores both marks
N.B. Before marking 7d check pages 18, 19 and 20 for additional answers by scrolling down. Extra answers MUST be annotated to show that they have been seen and credited back in the relevant question when appropriate. **✓ = 1 extra mark** **x = incorrect; scores 0** **NBOD = no added value or no further action needed; scores 0** **CON = if reference is made to the additional answer in the main text and this answer contradicts the other then deduct the original mark; = if NO reference is made to the additional answer in the main text and this answer contradicts the other then do NOT change the original mark**					
	d		$(d \sin\theta = \lambda)$ $3.3 \times 10^{-6} \sin\theta = 546 \times 10^{-9}$ $\sin\theta = 0.165$ $\theta = 9.5°$	C1 C1 A1	
			Total question 7	**15**	

8)

(a)		electrons have mass, photons have zero mass electrons have charge, photons are uncharged photons travel at speed of light	**B1** **B1**	**max** 2 marks from 3 marking points lower speed of electrons **not** required for mark
(b)	(i)	energy = eV $= 1.6 \times 10^{-19} \times 5000 = 8.0 \times 10^{-16}$ (J)	**C1** **A1**	**accept** 8×10^{-16} (J) (no SF error)
	(ii)	$\frac{1}{2}mv^2 = 8.0 \times 10^{-16}$ $v^2 = 1.76 \times 10^{+15}$ $v = 4.2 \times 10^{7}$ (m s^{-1})	**C1** **C1** **A1**	 evidence of calculation required
(c)	(i)	electron wavelength depends on its speed/momentum	**B1**	**accept** de Broglie equation with labels defined
	(ii)	$\lambda = h/mv$ $\lambda = 6.63 \times 10^{-34}/(9.1 \times 10^{-31} \times 4.2 \times 10^{7})$ $= 1.7 \times 10^{-11}$ (m)	**C1** **C1** **A1**	select formula substitution; **allow** 4×10^{7} **allow** 1.8×10^{-11} (m)
(d)		$E = hc/\lambda$ $\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^{8}/8.0 \times 10^{-16}$ $= 2.5 \times 10^{-10}$ (m)	**C1** **C1** **A1**	select equation substitute and manipulate answer 2.49×10^{-10} (m)
(e)	(i)	photoelectric effect / emission	**B1**	
	(ii)	$KE_{max} = hf - \varphi$ or $hf = \varphi + KE_{max}$ $9.0 \times 10^{-19} - 7.2 \times 10^{-19} = 1.8 \times 10^{-19}$ (J)	**C1** **A1**	can be copied from data sheet
	(iii)	Electrons in the metal have a range of energies most require more than the w.f. energy to escape from the surface/AW	**B1** **B1**	w.f. is minimum energy to escape from surface /AW max k.e. given when w.f. subtracted from photon energy **or** photon gives all of its energy to one electron
		Total	**19**	

9)

(a)	(i)	(atom releases energy when) electron moves from high to low level energy released is in form of a photon possible transitions are between n = 3 and n = 1, n = 3 and n = 2, n = 2 and n= 1	**B1** **B1** **B1**	can be illustrated on diagram by downward arrow connecting levels can be illustrated on diagram
(a)	(ii)1	$\varepsilon = hc/\lambda$ $= 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / 6.56 \times 10^{-7}$ $= 3.0(3) \times 10^{-19}$ (J)	 **C1** **A1**	choosing formula and substitution answer accept 3×10^{-19} (J) (no SF error)
(a)	(ii)2	from n = 3 to n = 2	**B1**	**allow** between n = 3 and n = 2 **allow** n = 2 to n = 3 or between n = 2 and n = 3 **if** there is no contradiction with answer given in 7ai

10)

a		All of the *rays/wavefronts/waves* are added together (at each point on the screen) when the path difference is an exact number of wavelengths the *rays/waves* interfere constructively giving maximum amplitude/intensity (at all other angles) when the path difference between rays is not an exact number of wavelengths the *rays/waves interfere destructively/cancel out* giving *a dark background/little to no intensity*	B1 B1 B1 B1 B1 B1	**max** 4 marks to include the second marking point **NOT** *superpose* or *interfere* for *added* as in stem of Q **allow** nλ **QWC mark** **allow** bright *line/light* **NOT** bright fringes **nor** maxima **NOT** when the path difference is (2n +1)λ/2 there is destructive interference/AW **allow** suitable annotation of diagram to score marks
b	**i 1**	two lines between 5 and 15 degrees (judge by eye)	B1	**allow** with label C missing; actual value is 12.5°
	i 2	select $n\lambda = d \sin\theta$ $579 \times 10^{-9} = d \sin 20 = 0.342\ d$ $d = 1.7 \times 10^{-6}$ (m)	C1 C1 A1	**allow** n = 1 in initial equation allow 1.69×10^{-6}
	ii	**E**	B1	
	iii	**D,E**	B1	
	iv	$E = 3.64 \times 10^{-19}$ J select $E = hc/\lambda$, $\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / 3.64 \times 10^{-19}$ $\lambda = 5.46 \times 10^{-7}$ m **D**	C1 B1 A1 A0	**accept** 546 nm; **N.B.** a correct unit must be present
	v	lines appear at the same *positions/frequencies* in the spectrum **emission**: *bright/coloured* lines (on dark background) **absorption**: *dark/black* lines (on *bright background/continuous spectrum*)	B1 B1	 **allow** comparison of backgrounds only **or** just a full description of absorption spectrum
	vi	$E = (3.1 + 4.7) \times 10^{-19}$ J $= 7.8 \times 10^{-19}$ J select $E = hc/\lambda$, $\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / 7.8 \times 10^{-19}$ $\lambda = 2.55 \times 10^{-7}$ m	B1 B1 A1	$E = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / 2.54 \times 10^{-7}$ giving $E = 7.8(3) \times 10^{-19}$ J ($f = 1.18 \times 10^{15}$ Hz) which equals $(3.1 + 4.7) \times 10^{-19}$ J
		Total question 4	**18**	

11)

a	**i**	λ is the (de Broglie) wavelength associated with a particle h is (a constant known as) the Planck constant mv is the momentum/mass x speed of the particle	B1 B1 B1	**allow** object/electron for particle **accept** velocity for speed **accept** m and v separately but the particle must appear with one of the quantities to score the mark
	ii	electrons passing through a (thin) sheet of graphite are diffracted producing *rings/pattern* (on a fluorescent screen)	B1 A1	any suitable situation **NOT** Au or Al, etc. what is observed + interpretation 1 mark. **Do not** award the A mark alone unless a plausible situation has been suggested. *Young slits* type experiments etc score 0/2
	iii 1	$eV = ½ mv^2$ $2eV/m = v^2$ so $v = \sqrt{(2 \times 1.6 \times 10^{-19} \times 5.0 \times 10^4/9.1 \times 10^{-31})}$ so $v = 1.3 \times 10^8$ (m s^{-1})	C1 C1 B1 A0	**allow** $eV = 8.0 \times 10^{-15}$ J for 1 mark **allow** $\sqrt{(2 \times 8.0 \times 10^{-15}/9.1 \times 10^{-31})}$ **or** evidence of correct calculation, e.g. $v = 1.325 \times 10^8$
	iii 2	$\lambda = h/mv = 6.63 \times 10^{-34}/ 1.3 \times 10^8 \times 9.1 \times 10^{-31}$ $\lambda = 5.6 \times 10^{-12}$ (m)	C1 A1	 **allow** 5.5×10^{-12} if 1.325×10^8 is used
	iii 3	λ of visible light 5.6×10^{-7} m so power of 10 = 5 or -5	B1 B1	**ecf aiii2**; **accept** 4 to 7 x 10^{-7} m **NOT** 10^{-7} **NOT** 10^5 on the answer line
b		The photoelectric effect Individual photons are absorbed by individual electrons in the metal surface, i.e. one to one interaction. Only photons with energies above the work function energy will cause photoelectron emission/idea of threshold frequency Hence u-v photons or blue photons will cause photoemission but red photons will not. Number of electrons emitted depends on light intensity A wave model does not explain instantaneous emission of electrons. A wave model does not explain a threshold frequency/wavelength for emission to occur	B1 B1 B1 B1 B1 B1 B1	QWC mark **allow** exp't description: uv light shone on a zinc plate connected to a gle **max** 3 from 6 marking points **allow** wave model does not explain no emission however bright the light if energy of photon below work function
		Total question 6	**16**	