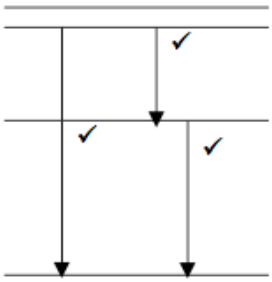
1)

(a)		ionisation energy = 13.6 eV ✓	**1**
(b)	(i)	 ✓ ✓ ✓	**8**
	(ii)	energy in Joules = 1.90 ✓ × 1.6 × 10^{-19} = 3.04 × 10^{-19} (J) ✓ (use of $E = hc/\lambda$) 3.04 × 10^{-19} = 6.63 × 10^{-34} × 3 × $10^{8}/\lambda$ ✓ (working/equation must be shown) λ = 6.54 × 10^{-7} m ✓✓ (2 or 3 sf for second mark) (accept 0.65 which gives an answer of λ = 1.91 × 10^{-6} m)	
		Total	**9**

2)

(a)		electrons can have wavelike properties and particle like properties ✓	**1**
(b)	(i)	(use of $\lambda = h/mv$) mv = 6.63 × $10^{-34}/1.2 \times 10^{-10}$ ✓ mv = 5.5 × 10^{-24} ✓ kg m s^{-1} ✓ (or N s)	**7**
	(ii)	v = 5.5 × $10^{-24}/9.11 \times 10^{-31}$ ✓ v = 6.1 × 10^{6} m s^{-1} ✓	
	(iii)	(use of $E = \frac{1}{2}mv^2$) $E = \frac{1}{2} \times 9.11 \times 10^{-31} \times (6.1 \times 10^{6})^2$ ✓ (must see working or equation) E = 1.6(9) × 10^{-17} J ✓ (no working max 1)	
		Total	**8**

3)

(a)	(i)	an electron/atom is at a higher level than the ground state ✓ **or** electron jumped/moved up to another/higher level	**1**
(a)	(ii)	electrons (or electric current) flow through the tube ✓ and collide with orbiting/atomic electrons or mercury atoms ✓ raising the electrons to a higher level (in the mercury atoms) ✓	**3**
(a)	(iii)	photons emitted from mercury atoms are in the **ultra violet** (spectrum) **or** high energy photons ✓ these photons are absorbed by the powder **or** powder changes frequency/wavelength ✓ and the powder emits photons in the visible spectrum ✓ incident photons have a variety of different wavelengths ✓	**max 3**
(b)	(i)	(use of $E = hf$) $-0.26 \times 10^{-18} - 0.59 \times 10^{-18}$ ✓ $= 6.63 \times 10^{-34} \times f$ ✓ $f = 0.33 \times 10^{-18}/(6.63 \times 10^{-34}) = 5.0 \times 10^{14}$ (Hz) ✓	**3**
(b)	(ii)	**one** arrow between n=3 and n=2 ✓ in correct direction ✓	**2**
		Total	**12**

4)

a	i	when electrons/atoms are in their lowest/minimum energy (state) **or** most stable (state) they (are in their ground state) ✓	**1**
a	ii	in either case an electron receives (exactly the right amount of) energy ✓ excitation promotes an (orbital) electron to **a higher energy/up a** level ✓ ionisation occurs (when an electron receives enough energy) **to leave** the atom ✓	**3**
b		electrons occupy discrete energy levels ✓ and need to absorb an exact amount of/enough energy to move to a higher level ✓ photons need to have certain frequency to provide this energy **or** e = hf ✓ energy required is the same for a particular atom or have different energy levels ✓ all energy of photon absorbed ✓ in 1 to 1 interaction or clear **a/the photon** and **an/the electron** ✓	**max 4**
c		energy $= 13.6 \times 1.60 \times 10^{-19} = 2.176 \times 10^{-18}$ (J) ✓ $hf = 2.176 \times 10^{-18}$ ✓ $f = 2.176 \times 10^{-18} \div 6.63 \times 10^{-34} = 3.28 \times 10^{15}$ Hz ✓ 3 sfs ✓	**4**
		Total	**12**

5)

a	(i)	absorbs enough energy (from the incident) electron(by collision) OR incident electron loses energy (to orbital electron) ✓ exact energy/10.1((eV) needed to make the transition/move up to level 2✓	2	For second mark must imply exact energy
a	(ii)	(*use of* $E_2 - E_1$) = *hf* -3.41 - - 13.6 = 10.19✓ energy of photon = $10.19 \times 1.6 \times 10^{-19} = 1.63 \times 10^{-18}$ (J) ✓ $6.63 \times 10^{-34} \times f = 1.63 \times 10^{-18}$ $f = 2.46 \times 10^{15}$ (Hz)✓ *(accept 2.5 but not 2.4)*	3	CE from energy difference but not from energy conversion
a	(iii)	Ek = $1.7 \times 10^{-18} - 1.63 \times 10^{-18}$✓ = 7.0×10^{-20} J✓	2	
a	(iv)	energy required is 12.09 eV/1.9×10^{-18} ✓ energy of incident electron is only 10.63 eV/energy of electron less than this (1.7×10^{-18} J)✓	2	State and explain must have consistent units i.e. eV or J
b	(i)	Electrons return to lower levels by different routes/cascade/not straight to ground state✓	1	
b	(ii)	3✓ n= 3 to n=1 or n=3 to n=2 and n=2 to n=1✓	2	no CE from first mark

6)

(a)	(electron) diffraction/interference/superposition ✓	**1**
(b)	(use of $\lambda = h/mv$) $\lambda = 6.63 \times 10^{-34}/(9.11 \times 10^{-31} \times 4.50 \times 10^{5})$ ✓ $\lambda = 1.6 \times 10^{-9}$ (m) ✓	**2**
(c)	$207 \times 9.11 \times 10^{-31}$ ✓ $\times v = 6.63 \times 10^{-34}/1.6 \times 10^{-7}$ ✓ v = 2200 (2170) (m s^{-1}) ✓	**3**
	Total	**6**

7)

a		(electron) diffraction / interference / superposition✓	1		Accept derfraction
b		(use of $\lambda=h/mv$) $\lambda=6.63 \times 10^{-34}/(9.11 \times 10^{-31} \times 2.5 \times 10^{5})$ ✓ $\lambda=2.9 \times 10^{-9}$ m ✓✓ (2 sig figs.)	3		
c		$v=2.5 \times 10^{5}/207$✓ v=1200 m s^{-1}✓ OR use $v=h/m\lambda$ with CE from 3(b)	2		Answer alone gets 2 marks

8)

a	(i)	ultraviolet / UV/ UV light/ ultra(-)violet✓	1		
a	(ii)	electron(in ground state) has moved/in to higher (energy) level/shell/orbital/state OR up level/shell/orbital/state✓	1		Ignore reference to photons
a	(iii)	(free) electrons collide with orbital electrons/mercury electrons/electrons in atom✓ transferring energy✓	2		Ignore any reference to photons
a	(iv)	(mercury) atoms have discrete/fixed/specific energy levels✓ when electrons change levels they lose an exact/fixed/specific/discrete/set amount of energy OR photons emitted with exact/fixed/specific/discrete/set amount of energy ✓ (leading to photons of) fixed/particular/certain/discrete/specific/unique frequencies✓	3		Each mark independent Don't accept characteristic for 3rd mark
b	(i)	(*use of λ=c/f*) $f=3 \times 10^{8} /(254 \times 10^{-9})$ ✓ $f= 1.18 \times 10^{15}$ (Hz)✓	2		AE penalty if give answer to 1 sig fig
b	(ii)	(*use of E=hf*) $E=6.63 \times 10^{-34} \times 1.18 \times 10^{15}= 7.82 \times 10^{-19}$J✓ $E= 7.82 \times 10^{-19}/1.6 \times 10^{-19}$✓ = 4.9 (4.875) eV	2		CE b(i) Range 4.8 - 5.0 acceptable
c		coating absorbs photons/uv light✓ and re-emits (photons) of low(er) energy/long(er) wavelength/low(er) frequency✓	2		Ignore any description of mechanism

9)

(a)	the mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication	
QWC	**descriptor**	**mark range**
good - excellent	Uses accurately appropriate grammar, spelling, punctuation and legibility. Uses the most appropriate form and style of writing to give an explanation or to present an argument in a well structured piece of extended writing. [May include formulae or equations]. Answer refers to at least 5 of the relevant points listed below.	**5 - 6**
modest - adequate	Only a few errors. Some structure to answer, style acceptable, arguments or explanations partially supported by evidence or examples. Answer refers to at least 3 or the relevant points listed below.	**3 - 4**
poor - limited	Several significant errors. Answer lacking structure, arguments not supported by evidence and contains limited information. Answer refers to no more than 2 of the relevant points.	**1 – 2**
incorrect, inappropriate or no response	No answer at all or answer refers to unrelated, incorrect or inappropriate physics.	**0**
	The explanation expected in a competent answer should include a coherent selection of the following physics ideas.	
	electron in atoms can only occupy certain (discrete) energy levels ✓	
	the ground state is the lowest energy state an electron/atom can occupy ✓	
	electrons collide with (orbital) electrons ✓	
	giving the electrons the energy necessary to move to a higher level ✓	
	electrons later return to a lower level/ground state losing energy ✓	
	by emitting photons of a characteristic/different/discrete/certain/varying frequencies **or** $\Delta E = hf$ **or** frequency depends on energy difference ✓	
(b) (i)	the 5.5 eV electron does not have enough energy to excite an (orbital) electron/atom ✓	**7**
	the 9.0 eV electron provide enough energy to excite an (orbital) electron/atom ✓	
(ii)	energy = $9.0 \times 1.6 \times 10^{-19}$ ✓ = 1.44×10^{-18} (J) ✓	
(iii)	$E = 1.44 \times 10^{-18} - 1.6 \times 10^{-19} = 1.28 \times 10^{-18}$ ✓ (J)	
	$6.63 \times 10^{-34} \times f = 1.28 \times 10^{-18}$ ✓	
	$f = 1.28 \times 10^{-18} / 6.63 \times 10^{-34} = 1.9 \times 10^{15}$ Hz ✓	
	Total	**12**

10)

a	**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. The candidate provides a comprehensive and coherent description which includes a clear explanation of constant energy level differences and how electrons can be excited by electron collisions. The link between the energy of a photon and its frequency should be clear. The description should include a clear explanation of the reason atoms of a given element emit photons of a characteristic frequency **or** there is a clear link between constant energy differences and photon frequency/wavelength (eg E=hf). The candidate should relate the energy **difference** between levels to the energy of emitted photons and state the energy difference is fixed/constant. **Intermediate Level (Modest to adequate): 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. The candidate provides an explanation of energy levels and how excitation takes place by electron collision with **atomic/orbital** electrons. The candidate explains how an orbital/atomic electron loses energy by emitting a photon.	**max 6**

		Low Level (Poor to limited): 1 or 2 marks The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. Some mention of energy levels and the idea of excitation of electron. Talk about excitation of atom instead of electron limits the mark to 1. **Incorrect, inappropriate of no response: 0 marks** No answer or answer refers to unrelated, incorrect or inappropriate physics. **The explanation expected in a competent answer should include a coherent account of the significance of discrete energy levels and how the bombardment of atoms by electrons can lead to excitation and the subsequent emission of photons of a characteristic frequency.** electrons bombard atoms of vapour and give energy to electrons in atom electrons move to a higher energy level electrons are excited excited electrons move down to lower energy levels losing energy by emitting photons photons have energy hf photons of characteristic frequencies emitted from atoms of a particular element this is because atoms have discrete energy levels which are associated with particular energy values	
b	i	energy required to (completely) remove an electron from atom/hydrogen ✓ ground state/lowest energy level ✓	**2**
b	ii	$13.6 \times 1.6 \times 10^{-19}$ ✓ $= 2.18 \times 10^{-18}$ (J) ✓ 3 sfs ✓	**3**
		Total	**11**