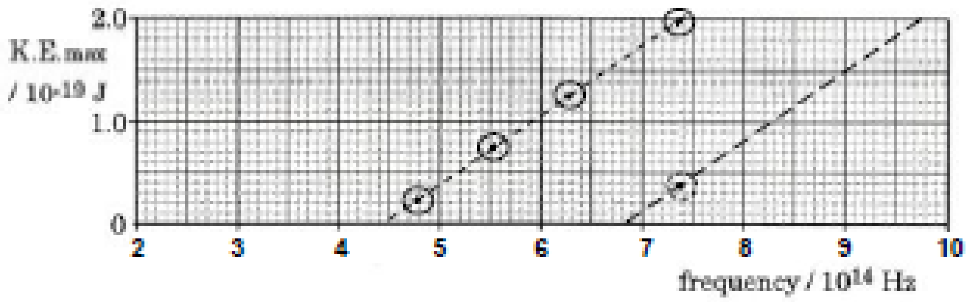
Marking Scheme

1.	*(a)*	(i)	Maximum k.e. of <u>emitted / photo electrons</u>	1
		(ii)	Energy of a photon[s]	1
		(iii)	[Minimum] energy needed to remove electron [from surface]. Don't accept from an atom	1
	(b)	(i)	I. Gradient calculation attempted (1) – no penalty for wrong powers of 10. $6.6\,[\pm 0.3] \times 10^{-34}$ [J s] (1) <u>agreeing with working</u>	2
			II. $f_{thresh} = 4.4 \times 10^{14}$ Hz (1) [$\pm 0.1 \times 10^{14}$ Hz] <u>or</u> valid algebraic method $\phi = 2.9 \times 10^{-19}$ J UNIT (1) ecf	2
		(ii)	I.  Correct point (1), parallel line (1)	2
			II. Ultraviolet [or UV]	1
			III. Lithium has higher work function / needs more energy to remove an electron	1

2.

(i)	$[\pi \times 22^2]$(1) [accept πr^2] $\times$ 14 (1) [$=21\,287$ m^3 s^{-1}] [21 287 $\rightarrow$ 1 mark]	2
(ii)	mass every second = 1.2 $\times$ 21000 [or as calculated in (i)] [= 25 200] kg s^{-1}	1
(iii)	Initial E_{k1} = ½ $\times$ 25 200 $\times$ 14^2 (1) e.c.f. from (ii) Final E_{k2} = ½ $\times$ 25 200 $\times$ 14^2 (1) e.c.f. from (ii) $\Delta E_k = 945 \times 10^3$ J s^{-1} (1) e.c.f. from E_{k1} and E_{k2} NB. "Solutions" based upon ½ $m \times (14 - 11)^2 \rightarrow 0$	3
(iv)	Useful power available = 614 250 J s^{-1} (1) e.c.f. from (iii) $N_{turbines} = \dfrac{1000 \times 10^6}{614250}$ [=1628] (1)	2
		[8]

3.

Question			Marking details	Marks Available
	(a)		Any 4 x (1) from: • light [energy] in discrete packets • one electron ejected by one photon OR photons don't co-operate • energy not accumulated [by electron] over time or emission from instant light shines • intensity has no effect on E_{kmax} or accept intensity affects number emitted per second • wave theory doesn't predict Einstein's equation or doesn't predict threshold frequency	[4]
	(b)	(i)	$E_{kmax} = (6.63 \times 10^{-34} \times 8.7 \times 10^{14} - 3.8 \times 10^{-19})$ (1) $E_{kmax} = 1.97 \times 10^{-19}$ [J] (1)	[2]
		(ii)	These photons eject electrons with smaller E_{kmax} (1) E_{kmax} same as previously with some explanation given (1)	[2]
		(iii)	Correct use of $c = f\lambda$ (1) e.g. to give λ_{thresh} = 523 [nm] OR $f_{400\text{ nm}} = 7.5 \times 10^{14}$ [Hz] OR $f_{700\text{ nm}} = 4.3 \times 10^{14}$ [Hz] Comparison of 400 [nm] with λ_{thresh} (1) or 7.5×10^{14} [Hz] with f_{thresh} (5.73×10^{14} [Hz]) or substitution of 7.5×10^{14} [Hz] into Einstein's equation. Conclusion : It can (1) [if reasoned]	[3]
			Question 4 Total	**[11]**

4. *(a)*		Electrons are emitted [from tin] (1). Electrons are negatively charged [**or** plate originally neutral] **or** electrons knocked out by photons (1) Plate left with a positive charge (1)	3
(b)	(i)	Work function: [Minimum] energy [or work] needed for an electron to escape [from metal surface]	1
	(ii)	$hf_{min} = \phi$ [or by impl.] or $0 = 6.63 \times 10^{-34} f_{min} - 7.1 \times 10^{-19}$ (1) $f_{min} = 1.07 \times 10^{15}$ Hz (1)	2
	(iii)	$1.5 \times 10^{-19} = hf - 7.1 \times 10^{-19}$ [or equiv. or by impl.] (1) $f = 1.3 \times 10^{15}$ Hz (1)	2
(c)	(i)	number per second = $\dfrac{0.64 \times 10^{-6}[\text{C s}^{-1}]}{1.6 \times 10^{-19}[\text{C}]}$	1
	(ii)	Number of photons per second = $4.0 \times 10^{12} \times 1200$ Multiplication by 1200 at any stage [or by impl.](1) Photon energy = 8.6×10^{-19} J [or by impl.] (1) UV energy per second = 4.1 m(1)W(1) [4.1×10^{-3} J s^{-1} ✓✓]	4
			[13]

5. (a)		$f_{Thresh} = \dfrac{\phi}{h}$ (1) [or by impl.] = $5.1[3] \times 10^{14}$ [Hz] (1)	2
(b)	(i)	Photon $E = 6.63 \times 10^{-34} \times 7.4 \times 10^{14}$ [$= 4.91 \times 10^{-19}$J][or by impl.](1) $E_{k\ max}$ [$= 4.91 \times 10^{-19} - 3.4 \times 10^{-19}$] $= 1.5 \times 10^{-19}$ [J] (1)	2
	(ii)	[A single] photon gives its energy to an electron (1) Some of the energy used to escape from the metal (1).	2
(c)	(i)	Points plotted at (5.1×10^{14}Hz, 0) and (7.4×10^{14} Hz, 1.5×10^{-19} J) (1) Allow e.c.f. from (a) and (b)(i) Straight line drawn through points (1) (One correct point only and a positive slope line = 1 mark)	2
	(ii)	h / the Planck constant	1
	(iii)	Straight line drawn with same gradient as (i) and to the right	1

6.	*(a)*		[Minimum] energy needed to release [or eject] electron from magnesium [or metal or surface or solid **not** atom]	1
	(b)		$E_{k\,max} = 6.63 \times 10^{-34} \times 1.16 \times 10^{15}$ [J] $- 5.9 \times 10^{-19}$ [J] (1) $E_{k\,max} = 1.79 \times 10^{-19}$ [J] (1)	2
	(c)		Photon energy < work function (1) don't accept photon energy in symbols. Accept not enough energy to liberate an electron. Don't accept $E_{k\,max}$ can't be negative. $E_{phot} = 5.4 \times 10^{-19}$ [J] **accept** $f_{thresh} = 8.9 \times 10^{14}$ [Hz] (1) If negative energy award 1 mark only	2
	(d)	(i)	Planck constant. **Accept** Planck's constant **or** h.	1
		(ii)	[–] work function. **Accept** [–] ϕ.	1
		(iii)	f_0 **or** minimum frequency to eject electron **or** threshold frequency	1

7.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
3	*(a)*		Photons have enough energy [or frequency or hf high enough] (1) to emit / release electrons (from metal surface) (1) These arrive at the anode / [collecting] (& give current) (1)	1 1	1		3		3
	(b)		Applying Einstein's equation i.e. 2.7 + 1.2 (= 3.9 eV) (1) Converting to J i.e. $\times 1.6 \times 10^{-19}$ (1) Answer = 9.4×10^{14} Hz (1) N.B. 5.9×10^{33} Hz $\rightarrow$ 1 mark only	1	1 1		3	2	
	(c)	(i)	Reverse polarity of supply [or equivalent, e.g. make collecting electrode negative / reversing the photocell] (1) [Increase pd] until current is [just] zero (1) Record the pd (from voltmeter) [or this is the stopping potential] (1)		3		3		3
		(ii)	(Alpha particles +ve so) opposite current (1) Current zero at smaller pd (1) More accurate if light intensity large (accept any insightful comment e.g. obtain activity and compensate / measure the dark current) [Accept - wait for activity to decrease] (1)			3	3		3
			Question 3 total	**3**	**6**	**3**	**12**	**2**	**9**

8.

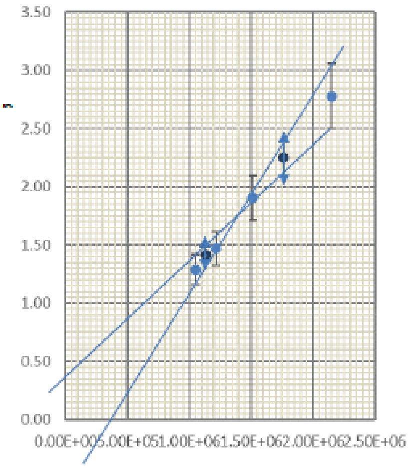
Question				Marking details	Marks Available
5	*(a)*	(i)		[Maximum] kinetic energy *of <u>emitted electron[s</u>*]	1
		(ii)		Photon energy	1
		(iii)		[Minimum] energy needed to release [**or** eject] <u>electron</u> from surface [**or** metal **or** solid]	1
	(b)			$\phi = hf_0$ **or** by implication (1) $f = 3f_0$ (1)	2
	(c)	(i)	I	attempt at gradient calculation even if slips, e.g. in 10^n (1) $h = 6.8\ [\pm 0.2] \times 10^{-34}$ [J s] (1)	2
			II	$\phi = 3.1\ [\pm 0.1] \times 10^{-19}$ [J] Don't accept a negative ϕ	1
		(ii)		$\phi_{sodium} = \phi_{caesium} + 0.6$ [or 0.7] $\times 10^{-19}$ J **or** parallel line **or** use of equation (1) $\phi_{sodium} = 3.7\ [\pm 0.3] \times 10^{-19}$ [J] **ecf** (1)	2
				Question 5 Total	**[10]**

9.

(a)	(i)	ϕ is [minimum] energy needed to release an electron <u>from surface</u> [or <u>from metal</u> or <u>from material</u>]. (1) No marks for giving meaning of f_0. So [minimum] *photon* energy needed is ϕ. (1) So $hf_0 = \phi$ or $E_{photon} = hf$ (1)	[3]
	(ii)	Award 2 x (1) of: • More photons per second • Individual photon energies unchanged • E_{kmax} depends on energy of individual photon or $E_{kmax} = hf - \phi$ does not include intensity. Accept: Photons don't co-operate [in releasing electrons].	[2]
(b)		Increase / adjust pd until nano-ammeter shows zero current [or equiv.] (1) Read voltmeter (1) or by implication $E_{kmax} = eV$ (1)	[3]
(c)	(i)	Gradient = 6.7 [± 0.2] x 10^{-34} [J s] (1) Mention of Planck's constant and sensible comparison (1)	[2]
	(ii)	$\phi = 4.1\ [\pm 0.2] \times 10^{-19}$ [J] (1) barium but only award mark if some reasoning given e.g. correct reference to intercept (1)	[2]

Question				Marking details	Marks available					
					AO1	AO2	AO3	Total	Maths	Prac
7	*(a)*			energy needed (1) ….. …. to remove an electron from a surface(1)	2			2		
	(b)	(i)		Energy of one photon = 4.8×10^{-19} [J] (1) Number of photons = 5.2×10^{8} (1)		2		2	2	
		(ii)	I	Threshold frequency = 4.4×10^{14} [Hz] (1) Work function = $hf_0 = 2.9 \times 10^{-19}$ [J] (1)		2		2	2	
			II	Line drawn with intercept greater than 4.4×10^{14} Hz (1) Line has same gradient (1)		2		2	1	
			III	Photon energy would stay the same (1) Same surface or work function would stay the same (1)		2		2		
				Question 7 total	**2**	**8**	**0**	**10**	**5**	**0**

11.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
7	*(a)*	(i)	1.76 and 1.12 [1] 0.23 and 0.14 [1]			2	2	2	2
		(ii)	 Both points correct ± ½ small square division [1] Both error bars correct [1]		2		2	2	2
		(iii)	Line of maximum gradient correct [1] Line of minimum gradient correct [1] Allow ecf on plots and error bars for 1 mark only if imperfect		2		2		2
	(b)	(i)	Correct gradients (expect 1.73×10^{-6}, 0.98×10^{-6} but allow ecf on lines, just check for consistency) [2] Correct value of h obtained expect 7.2×10^{-34} [J s] (regardless of method, allow ecf but check consistent with lines) [1] Correct % uncertainty (expect around 27%) or $2 \times$ correct values of h obtained e.g. 9.1 and 5.3 [1] (just check that these are consistent with the drawn lines) Final expression consistent with sig figs only 1 or 2 sig figs for uncertainty (allow ecf) e.g. $(7.2 \pm 1.9) \times 10^{-34}$ [J s], $(7.2 \pm 1.8) \times 10^{-34}$ [J s], $(7.2 \pm 2.0) \times 10^{-34}$ [J s], $(7 \pm 2) \times 10^{-34}$ [J s] [1]			5	5	4	5
		(ii)	**Any 4 × (1) from:** • Straight line ✓ • Through all error bars ✓ • Straddles origin / best fit line goes through origin ✓ • Value of h consistent (with data booklet) / gradient = $\frac{hc}{e}$ accept h is slightly large ✓ • Large uncertainty or scatter in data ✓			4	4	4	4
	(c)		Eye sensitivity changes with wavelength or long/some wavelengths invisible Don't accept reference to human error			1	1		
	(d)	(i)	Method correct (obtaining gradient or substituting values) e.g. $\frac{6.6 \times 10^{-19}}{10 \times 10^{14}}$ or $h \times 10 \times 10^{14} = 4.6 \times 10^{-19} + 2 \times 10^{-19}$ [1] $h = 6.6 \times 10^{-34}$ [J s] or other consistent value [1]		2		2	2	2
		(ii)	$h \times 6.9 \times 10^{14} = 4.57 \times 10^{-19}$ J OR y-intercept $= 4.6 \times 10^{-19}$ J [1] Photon energy is too low [1] to release electrons [1]	1 1	1		3	1	3
			Question 7 total	**2**	**7**	**12**	**21**	**15**	**21**

12.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
3	*(a)*	(i)	The emission of electrons from a surface due to light or em rad^n	1			1		
		(ii)	Energy of light is in the form of photons/packets of energy = hf (1) The work function ϕ is needed for the electron to escape (1) $E_{k\,max}$ is the energy remaining for the electron (1)	3			3		
	(b)		Polarity is incorrect/All the electrons will reach collecting electrode (1) No ammeter in circuit (1) Voltmeter not connected correctly (1) No variable supply (1)			4	4		4
	(c)	(i)	Axis labelled correctly with units and suitable scale so that data points occupy half of the axis (1) All points plotted correctly to within ±½ small square division (1) Good line of fit consistent with data (1)		3		3	3	3
		(ii)	Straight line graph of positive gradient (1) Passes close to all data points (1) Cannot determine if passes through origin (allow ecf) does not pass through origin/clear negative y intercept (must be consistent with graph)' (1)			3	3	1	3
		(iii)	Planck constant = gradient (implied) (1) Large triangle used [or 2 equivalent suitable points clearly indicated on the graph] and correct values for gradient calculation (1) Gradient calculated correctly and Planck constant = 6.6 (± 0.2) × 10^{-34} (J s) (1)		3		3	2	2
		(iv)	5% of Planck constant (6.63 × 10^{-34} J s) determined (± 0.33 × 10^{-34}) (1) Valid conclusion e.g. value obtained is within 5% (1)		1	1	2		
			Question 3 total	**4**	**7**	**8**	**19**	**7**	**14**

13.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
8	*(a)*	(i)	No emission if photon energy < ϕ [or emission only if photon energy > ϕ](1) Convincing argument, clearly implying that photon energy = hf and leading to no emission if $f < \frac{\phi}{h}$ (1) Increasing light intensity just gives more photons or doesn't change [energy of] individual photons or doesn't help because photons don't co-operate (1)	3			3		
		(ii)	Photon energy = 4.37×10^{-19} [J] (1) No emission by Ca or Zn (or equiv) (1) $KE_{max} < 0.56 \times 10^{-19}$ J or $\phi > 3.81 \times 10^{-19}$ J or equivalent, e.g. V_S = 0.78 V (Cs), 0.43 V (K), 0.21 V (Ba) (1) Therefore Ba (1) [award mark only if attempted justification] See below:			4	4	2	
	(b)	(i)	Acceptable straight line through points (going through origin would be unacceptable)		1		1	1	1
		(ii)	Straight line as predicted (1) But not through origin (or non-zero intercept). Equation predicts through origin (or proportionality) (1)			2	2	1	2
		(iii)	Data from graph put into $\frac{\Delta V}{\Delta f}$ irrespective of slips such as incorrect powers of 10 (1) Accept between 3.90×10^{-15} and 4.40×10^{-15} [V Hz^{-1}] and to either 2 or 3 sig figs (1) $h = 6.64 \times 10^{-34}$ J s ecf from gradient (1)			3	3	2	3
			Question 8 total	**3**	**1**	**9**	**13**	**6**	**6**

Additional marking guidance for 8*(a)*(ii)

Method 1

$hf = 4.37 \times 10^{-19}$ J (1)
For Barium $hf - \phi = 0.34 \times 10^{-19}$ J (1)
$V_{stop} = 0.21$ V (1)
Therefore barium (1)

Method 2

$hf = 4.37 \times 10^{-19}$ J (1)
$h\phi < 4.37 \times 10^{-19}$ J or not Ca or Zn (1)
For potassium, Either $hf - \phi = 0.69 \times 10^{-19}$ J
or $V_{stop} = 0.43$ V (1)
Therefore barium (1)

Method 3

$hf = 4.37 \times 10^{-19}$ J (1)
$h\phi < 4.37 \times 10^{-19}$ J or not Ca or Zn (1)
$E_k < 0.56 \times 10^{-19}$ J or $\phi > 3.81 \times 10^{-19}$ J (1)
[Don't penalise $E_k = 0.56 \times 10^{-19}$ J or $\phi = 3.81 \times 10^{-19}$ J if seen]
Therefore barium (1)

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
5.	*(a)*		[Minimum] energy needed to remove an electron [from the surface or from the metal] Don't accept reference to atoms or ionisation	1			1		
	(b)		Photon energy needed = 3.2×10^{-19} J + 1.5×10^{-19} J [= 4.7×10^{-19} J] or substitution of data into $E_{k\,max} = hf - \phi$ or by implication (1) $f = 7.1 \times 10^{14}$ [Hz] (1)		2		2	2	
	(c)	(i)	Photons per second = $\frac{0.3\text{ [W]}}{4.7 \times 10^{-19}\text{ [J]ecf}}$ (1) = 6.4×10^{17} [s^{-1}] Accept 6.5×10^{17} [s^{-1}] (1)		2		2	2	
		(ii)	Number of electrons per second = $\frac{0.8 \times 10^{-6}\text{ [A]}}{1.6 \times 10^{-19}\text{ [C]}}$ or by implication Accept slips of powers of 10 (1) = 5.0×10^{12} [s^{-1}] (1) Assumes all emitted electrons captured [or equivalent] (1)		3		3	2	
		(iii)	7.8×10^{-6} [or 7.8×10^{-4} %] ecf on *(c)*(i) and *(c)*(ii) or 8.3×10^{-6} [or 8.3×10^{-4} %] if 6×10^{17} used, ecf on *(c)*(ii)		1		1	1	
			Question 5 total	**1**	**8**	**0**	**9**	**7**	**0**