CAMBRIDGE INTERNATIONAL AS & A LEVEL PHYSICS · 9702

PHYSICS



MARK SCHEME

22 QUANTUM PHYSICS

SCORE	PERCENTAGE
/	%

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337. 9702_w17_MS_42 Q: 11

	Answer	Marks
(a)(i)	circles drawn only around the top left and bottom right diodes	B1
(a)(ii)	B shown as (+)ve and A shown as (–)ve	B1
(b)(i)	$V_{r.m.s.}$ (= 5.6 / √2) = 4.0 V	A1
(b)(ii)	380 = 2π*f* **or** *f* = 60.5 Hz	C1
	number (= 2*f*) = 120	A1
(c)(i)	peak values (all) unchanged	B1
	(all) minima shown at 4.0 V	B1
	three lines from near peak showing concave curves after leaving dotted line not 'kinked' and not cutting the peak reaching candidate's minimum at the point where the decay meets the next dotted line	B1
	three lines drawn along the dotted lines showing rise in voltage from minima back to peak values	B1
(c)(ii)	mean p.d. is higher **or** r.m.s. p.d. is higher **or** capacitor supplies energy to resistor	M1
	so (mean) power increases	A1

338. 9702_s21_MS_41 Q: 12

	Answer	Marks
(a)	• frequency determines energy of photon • intensity determines number of photons (per unit time) • intensity does not determine energy of a photon *Any two points, 1 mark each*	B2
	kinetic energy (of the electron) depends on the energy of one photon	B1
(b)(i)	$E = hc / \lambda$ **or** $E = hf$ **and** $c = f\lambda$	C1
	$E = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (250 \times 10^{-9})$	C1
	$(= 7.96 \times 10^{-19}$ J) = 5.0 eV	A1
(b)(ii)	E_{MAX} = photon energy – work function	C1
	work function = 5.0 – 1.4 = 3.6 eV	A1

339. 9702_s21_MS_43 Q: 12

	Answer	Marks
(a)	• frequency determines energy of photon • intensity determines number of photons (per unit time) • intensity does not determine energy of a photon *Any two points, 1 mark each*	B2
	kinetic energy (of the electron) depends on the energy of one photon	B1
(b)(i)	$E = hc / \lambda$ **or** $E = hf$ **and** $c = f\lambda$	C1
	$E = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (250 \times 10^{-9})$	C1
	$(= 7.96 \times 10^{-19}$ J) $= 5.0$ eV	A1
(b)(ii)	E_{MAX} = photon energy – work function	C1
	work function = 5.0 – 1.4 = 3.6 eV	A1

340. 9702_w21_MS_42 Q: 9

	Answer	Marks
(a)(i)	emission of electrons (from a metal surface)	B1
	when electromagnetic radiation is incident (on electrons)	B1
a(ii)	<u>minimum</u> energy required for an electron to leave surface	B1
(b)(i)	threshold (frequency)	B1
(b)(ii)	• photons are (discrete) packets of energy • energy of photons depends on frequency (of EM radiation) • electrons can only absorb a single photon (of energy) *Any two points, 1 mark each*	B2
	emission only possible if photon energy is at least the work function	B1
(b)(iii)	work function = hf_0 $= 6.63 \times 10^{-34} \times 6.93 \times 10^{14}$	C1
	$= 4.59 \times 10^{-19}$ (J) $= 4.59 \times 10^{-19} / 1.60 \times 10^{-19}$ (eV) $= 2.87$ eV	A1

341. 9702_m20_MS_42 Q: 10

	Answer	Marks
(a)	energy of a photon required to remove an electron	B1
	either: energy to remove electron from a surface *or*: <u>minimum</u> energy to remove electron *or*: energy to remove electron with zero <u>kinetic</u> energy	B1
(b)(i)	Correct read off from graph of f as 5.45×10^{14} Hz when $E_{MAX} = 0$ $5.45 \times 10^{14} \times 6.63 \times 10^{-34}$	C1
	$= \mathbf{3.6 \times 10^{-19}}$ J	A1
(b)(ii)	$3.6 \times 10^{-19} / 1.6 \times 10^{-19} = 2.3$ eV so potassium	A1
(c)(i)	each photon has same energy so no change	B1
(c)(ii)	more photons (per unit time) so (rate of emission) increases	B1

342. 9702_s19_MS_43 Q: 11

	Answer	Marks
(a)	Any three points from: • (max) energy of emitted electrons depends on frequency • (max) energy of emitted electrons does not depend on intensity • rate of emission of electrons depends on intensity (at constant frequency) • existence of frequency below which no emission of electrons • instantaneous emission of electrons • increasing the frequency at constant intensity decreases the rate of emission of electrons	B3
(b)(i)	photon energy $= hc / \lambda$	C1
	$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (380 \times 10^{-9})$ $(= 5.23 \times 10^{-19}\ \text{J})$	C1
	$= 3.3\ \text{eV}$	A1
(b)(ii)	photon energy must be greater than work function (energy)	B1
	so sodium and calcium	B1
(c)	$\lambda = h / p$	C1
	$p = (6.63 \times 10^{-34}) / (380 \times 10^{-9})$ $= 1.74 \times 10^{-27}\ \text{N s}$	C1
	force $= 1.74 \times 10^{-27} \times 7.6 \times 10^{14}$ $= 1.3 \times 10^{-12}\ \text{N}$	A1

343. 9702_w19_MS_41 Q: 11

	Answer	Marks
(a)	energy (of photon) required to remove electron	M1
	from a surface **or** reference to minimum energy **or** reference to zero kinetic energy	A1
(b)(i)	**1.** photon energy $= hc / \lambda$	C1
	$= (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (280 \times 10^{-9})$ $= 7.1 \times 10^{-19}\ \text{J}$	A1
	2. electron energy $= (7.1 - 5.5) \times 10^{-19}\ \text{J}$	C1
	$\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = (7.1 - 5.5) \times 10^{-19}$	C1
	$v = 5.9 \times 10^{5}\ \text{m s}^{-1}$	A1
(b)(ii)	energy is required to bring electron to the surface	B1
(c)	no change | decreases increases | decreases	B4

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344. 9702_w19_MS_43 Q: 11

	Answer	Marks
(a)	energy (of photon) required to remove electron	M1
	from a surface **or** reference to minimum energy **or** reference to zero kinetic energy	A1
(b)(i)	**1.** photon energy $= hc / \lambda$	C1
	$= (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (280 \times 10^{-9})$ $= 7.1 \times 10^{-19}$ J	A1
	2. electron energy $= (7.1 - 5.5) \times 10^{-19}$ J	C1
	$½ \times 9.11 \times 10^{-31} \times v^2 = (7.1 - 5.5) \times 10^{-19}$	C1
	$v = 5.9 \times 10^{5}$ m s^{-1}	A1
(b)(ii)	energy is required to bring electron to the surface	B1
(c)	no change / decreases increases / decreases	B4

345. 9702_s18_MS_42 Q: 10

	Answer	Marks
(a)	emission of electron	B1
	when electromagnetic radiation incident (on surface)	B1
(b)(i)	packet/quantum/discrete amount of energy	M1
	of electromagnetic radiation	A1
(b)(ii)	$E = hc / \lambda$	C1
	$= (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (420 \times 10^{-9})$ $= 4.7 \times 10^{-19}$ J	A1
(b)(iii)	sodium: yes zinc: no	B1

346. 9702_m17_MS_42 Q: 10

	Answer	Marks
(a)	packet / quantum of energy	M1
	of electromagnetic radiation	A1
(b)(i)	light is re-emitted in all directions / only part of the re-emitted light is in the direction of the beam	B1
(b)(ii)	an arrow between –3.40 eV and –1.51 eV and an arrow between –3.40 eV and –0.85 eV	B1
	all arrows shown point 'upwards'	B1
(b)(iii)	$E = hc / \lambda$ *or* $E = hf$ and $c = f\lambda$	C1
	$2.60 \times 1.60 \times 10^{-19} = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / \lambda$	C1
	$\lambda = 4.8 \times 10^{-7}$ m	A1

347. 9702_s17_MS_42 Q: 10

	Answer	Marks
(a)	two from: • frequency below which electrons not ejected • maximum energy of electron depends on frequency • maximum energy of electrons does not depend on intensity • instantaneous emission of electrons	B2
(b)(i)	(λ_0 is the) threshold wavelength **or** wavelength corresponding to threshold frequency **or** maximum wavelength for emission of electrons	B1
(b)(ii)1.	intercept = $1/\lambda_0 = 2.2 \times 10^6\,m^{-1}$ $\lambda_0 = 4.5 \times 10^{-7}$ m or 450 nm	A1
(b)(ii)2.	gradient = hc	C1
	gradient = 2.0×10^{-25} or correct substitution into gradient formula	C1
	$h = (2.0 \times 10^{-25}) / (3.0 \times 10^8) = 6.7 \times 10^{-34}$ J s	A1
(c)	line: same gradient	B1
	straight line, positive gradient, intercept at greater than 2.2×10^6 when candidate's line extrapolated	B1

348. 9702_m16_MS_42 Q: 11

(a) minimum frequency for electron(s) to be emitted (from surface) M1
reference to frequency of electromagnetic radiation / photon A1

or

frequency causing emission of electron(s)
from surface with zero kinetic energy (M1)
reference to frequency of electromagnetic radiation / photon (A1) [2]

(b) (i) positive intercept on $(1/\lambda)$-axis (when extrapolated) B1
straight line with positive gradient B1 [2]

(ii) gradient = hc where c is the speed of light B1 [1]

(iii) maximum kinetic energy when electron emitted from surface B1
energy is required to bring an electron to the surface B1 [2]

(iv) each photon has more energy M1
fewer photons per unit time M1
fewer electrons per unit time / less current A1 [3]

349. 9702_w16_MS_41 Q: 10

(a) electromagnetic radiation/photons incident on a surface B1

causes emission of electrons (from the surface) B1 [2]

(b) $E = hc/\lambda$

$= (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(436 \times 10^{-9})$ C1

$= 4.56 \times 10^{-19}$ J $(4.6 \times 10^{-19}$ J) A1 [2]

(c) (i) $\Phi = hc/\lambda_0$

$\lambda_0 = (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(1.4 \times 1.60 \times 10^{-19})$ C1

$= 890$ nm A1 [2]

(ii) $\lambda_0 = (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(4.5 \times 1.60 \times 10^{-19})$

$= 280$ nm A1 [1]

(d) caesium:
wavelength of photon less than threshold wavelength (or v.v.)
or
$\lambda_0 = 890$ nm > 436 nm
so yes A1

tungsten:
wavelength of photon greater than threshold wavelength (or v.v.)
or
$\lambda_0 = 280$ nm < 436 nm
so no A1 [2]

350. 9702_w16_MS_43 Q: 10

(a) electromagnetic radiation/photons incident on a surface B1

causes emission of electrons (from the surface) B1 [2]

(b) $E = hc / \lambda$

$= (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (436 \times 10^{-9})$ C1

$= 4.56 \times 10^{-19}$ J $(4.6 \times 10^{-19}$ J) A1 [2]

(c) **(i)** $\Phi = hc / \lambda_0$

$\lambda_0 = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (1.4 \times 1.60 \times 10^{-19})$ C1

$= 890$ nm A1 [2]

(ii) $\lambda_0 = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (4.5 \times 1.60 \times 10^{-19})$

$= 280$ nm A1 [1]

(d) caesium:
wavelength of photon less than threshold wavelength (or v.v.)
or
$\lambda_0 = 890$ nm > 436 nm
so yes A1

tungsten:
wavelength of photon greater than threshold wavelength (or v.v.)
or
$\lambda_0 = 280$ nm < 436 nm
so no A1 [2]

351. 9702_s21_MS_42 Q: 11

	Answer	Marks
(a)	to produce a 3-dimensional image of structure/body	**B1**
(b)	X-rays (are used)	**B1**
	scanning in sections	**B1**
	scanning from many angles	**B1**
	image of each section is 2-dimensional	**B1**
	scanning repeated for many sections **or** images of many sections combined together	**B1**

352. 9702_s21_MS_42 Q: 12

	Answer	Marks
(b)(ii)	$p = h / \lambda$	C1
	$= (6.63 \times 10^{-34}) / (2.2 \times 10^{-12})$ $= 3.0 \times 10^{-22}$ N s	A1
	or	
	$p = E / c$	(C1)
	$= (0.57 \times 10^{6} \times 1.60 \times 10^{-19}) / (3.00 \times 10^{8})$ $= 3.0 \times 10^{-22}$ N s	(A1)
(c)(i)	mass (of Sm-157 nucleus) $= 157 \times 1.66 \times 10^{-27}$ **or** mass (of Sm-157 nucleus) $= 0.157 / (6.02 \times 10^{23})$	C1
	recoil speed $= (3.00 \times 10^{-22}) / (157 \times 1.66 \times 10^{-27})$ $= 1.2 \times 10^{3}$ m s^{-1}	A1
(c)(ii)	$(1.2 \times) 10^{3}$ m s^{-1} is <u>much</u> less than $(3.0 \times) 10^{8}$ m s^{-1}	B1

353. 9702_w21_MS_41 Q: 10

	Answer	Marks
(a)(i)	photoelectric effect	B1
(a)(ii)	electron diffraction	B1
(b)(i)	$\lambda = h / p$	M1
	h is the Planck constant	A1
(b)(ii)	de Broglie (wavelength)	B1
(c)(i)	$½mv^2 = eV$	C1
	$½ \times 9.11 \times 10^{-31} \times v^2 = 1.60 \times 10^{-19} \times 4800$ <u>so</u> $v = 4.1 \times 10^{7}$ m s^{-1}	A1
(c)(ii)	$\lambda = h / mv$ $= 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 4.1 \times 10^{7})$	C1
	$= 1.8 \times 10^{-11}$ m	A1

354. 9702_w21_MS_43 Q: 10

	Answer	Marks
(a)(i)	photoelectric effect	B1
(a)(ii)	electron diffraction	B1
(b)(i)	$\lambda = h / p$	M1
	h is the Planck constant	A1
(b)(ii)	de Broglie (wavelength)	B1
(c)(i)	$½mv^2 = eV$	C1
	$½ \times 9.11 \times 10^{-31} \times v^2 = 1.60 \times 10^{-19} \times 4800$ <u>so</u> $v = 4.1 \times 10^{7}$ m s^{-1}	A1
(c)(ii)	$\lambda = h / mv$ $= 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 4.1 \times 10^{7})$	C1
	$= 1.8 \times 10^{-11}$ m	A1

355. 9702_s19_MS_41 Q: 11

	Answer	Marks
(a)	Any three points from: • (max) energy of emitted electrons depends on frequency • (max) energy of emitted electrons does not depend on intensity • rate of emission of electrons depends on intensity (at constant frequency) • existence of frequency below which no emission of electrons • instantaneous emission of electrons • increasing the frequency at constant intensity decreases the rate of emission of electrons	B3
(b)(i)	photon energy $= hc / \lambda$	C1
	$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (380 \times 10^{-9})$ $(= 5.23 \times 10^{-19}\ \text{J})$	C1
	$= 3.3\ \text{eV}$	A1
(b)(ii)	photon energy must be greater than work function (energy)	B1
	so sodium and calcium	B1
(c)	$\lambda = h / p$	C1
	$p = (6.63 \times 10^{-34}) / (380 \times 10^{-9})$ $= 1.74 \times 10^{-27}\ \text{N s}$	C1
	force $= 1.74 \times 10^{-27} \times 7.6 \times 10^{14}$ $= 1.3 \times 10^{-12}\ \text{N}$	A1

356. 9702_s19_MS_42 Q: 11

	Answer	Marks
(a)	packet/quantum of energy	M1
	of electromagnetic radiation	A1
(b)(i)	$E = hc / \lambda$	C1
	$1.18 \times 1.60 \times 10^{-13} = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / \lambda$ $\lambda = 1.05 \times 10^{-12}\ \text{m}$	A1
(b)(ii)	$\lambda = h / p$ **or** $E = pc$	C1
	$p = (6.63 \times 10^{-34}) / (1.05 \times 10^{-12})$ **or** $p = (1.18 \times 1.60 \times 10^{-13}) / (3.00 \times 10^{8})$ leading to $p = 6.3 \times 10^{-22}\ \text{N s}$	B1
(c)	$6.3 \times 10^{-22} = 60 \times 1.66 \times 10^{-27} \times v$	C1
	$v = 6.3 \times 10^{3}\ \text{m s}^{-1}$	A1

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357. 9702_w17_MS_41 Q: 11

	Answer	Marks
(a)	packet/quantum of energy of electromagnetic/EM radiation	B1
(b)(i)	$E = hf$ $1.1 \times 10^6 \times 1.60 \times 10^{-19} = 6.63 \times 10^{-34} \times f$	C1
	$f = 2.7 \times 10^{20}$ (2.65×10^{20}) Hz	A1
(b)(ii)	$p = h/\lambda = hf/c$ $= (6.63 \times 10^{-34} \times 2.65 \times 10^{20})/(3.00 \times 10^8)$ **or** $p = E/c$ $= (1.1 \times 1.60 \times 10^{-13})/(3.00 \times 10^8)$	C1
	$p = 5.9 \times 10^{-22}$ (5.87×10^{-22}) N s	A1
(c)	$123 \times 1.66 \times 10^{-27} \times v = 5.87 \times 10^{-22}$	C1
	$v = 2.9 \times 10^3$ m s^{-1}	A1

358. 9702_w17_MS_42 Q: 10

	Answer	Marks
(a)	λ_0 marked and graph line passing through $E_{MAX} = 0$ at $\lambda = \lambda_0$	B1
	graph line with λ always < λ_0	B1
	negative gradient with correct concave curvature	B1
(b)	curve with negative gradient and correct concave curvature	M1
	not touching either axis	A1

359. 9702_w17_MS_43 Q: 11

	Answer	Marks
(a)	packet/quantum of energy of electromagnetic/EM radiation	B1
(b)(i)	$E = hf$ $1.1 \times 10^6 \times 1.60 \times 10^{-19} = 6.63 \times 10^{-34} \times f$	C1
	$f = 2.7 \times 10^{20}$ (2.65×10^{20}) Hz	A1
(b)(ii)	$p = h/\lambda = hf/c$ $= (6.63 \times 10^{-34} \times 2.65 \times 10^{20})/(3.00 \times 10^8)$ **or** $p = E/c$ $= (1.1 \times 1.60 \times 10^{-13})/(3.00 \times 10^8)$	C1
	$p = 5.9 \times 10^{-22}$ (5.87×10^{-22}) N s	A1
(c)	$123 \times 1.66 \times 10^{-27} \times v = 5.87 \times 10^{-22}$	C1
	$v = 2.9 \times 10^3$ m s^{-1}	A1

360. 9702_w18_MS_42 Q: 11

	Answer	Marks
(a)	discrete amount/quantum/packet of energy	M1
	of electromagnetic radiation	A1
(b)	mostly dark/dark background	B1
	coloured lines	B1
(c)(i)	6	A1
(c)(ii)	**1.** maximum photon energy = 13.6 – 0.85 (= 12.75 eV)	C1
	maximum kinetic energy = (13.6 – 0.85) – 5.6 = 7.2 eV	A1
	2. energy = hc / λ	C1
	$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / [(13.6 - 0.85) \times 1.60 \times 10^{-19}]$	C1
	$= 9.8 \times 10^{-8}$ m	A1

361. 9702_s17_MS_41 Q: 11

	Answer	Marks
(a)	electrons (in gas atoms/molecules) interact with photons	B1
	photon energy causes electron to move to higher energy level/to be excited	B1
	photon energy = difference in energy of (electron) energy levels	B1
	when electrons de-excite, photons emitted in all directions (so dark line)	B1
(b)(i)	photon energy $\propto 1 / \lambda$	C1
	energy = 1.68 eV	A1
	or	
	$E = hc / \lambda$ $E = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / (740 \times 10^{-9})$ $= 2.688 \times 10^{-19}$ J	(C1)
	energy = 1.68 eV	(A1)
(b)(ii)	3.4 eV → 1.5 eV 3.4 eV → 0.85 eV 3.4 eV → 0.54 eV *all correct and none incorrect 2/2* *2 correct and 1 incorrect or only 2 correctly drawn 1/2*	B2

362. 9702_s17_MS_42 Q: 11

	Answer	Marks
(a)	loss of (electric) potential energy = gain in kinetic energy **or** $qV = ½ mv^2$ **or** $E_K = p^2 / 2m = qV$	**B1**
	$p = mv$ with algebra leading to $p = \sqrt{(2mqV)}$	**B1**
(b)(i)	particle/electron has a wavelength (associated with it)	**B1**
	dependent on its momentum **or** when/because particle is moving	**B1**
(b)(ii)	$p = (2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times 120)^{1/2}$	**C1**
	$\lambda = (6.63 \times 10^{-34}) / (5.91 \times 10^{-24})$	**C1**
	$= 1.12 \times 10^{-10}$ m	**A1**
(c)	wavelength is similar to separation of atoms	**M1**
	so diffraction observed	**A1**

363. 9702_s17_MS_43 Q: 11

	Answer	Marks
(a)	electrons (in gas atoms/molecules) interact with photons	**B1**
	photon energy causes electron to move to higher energy level/to be excited	**B1**
	photon energy = difference in energy of (electron) energy levels	**B1**
	when electrons de-excite, photons emitted in all directions (so dark line)	**B1**
(b)(i)	photon energy $\propto 1 / \lambda$	**C1**
	energy = 1.68 eV	**A1**
	or	
	$E = hc / \lambda$ $E = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / (740 \times 10^{-9})$ $= 2.688 \times 10^{-19}$ J	**(C1)**
	energy = 1.68 eV	**(A1)**
(b)(ii)	3.4 eV → 1.5 eV 3.4 eV → 0.85 eV 3.4 eV → 0.54 eV *all correct and none incorrect 2/2* *2 correct and 1 incorrect or only 2 correctly drawn 1/2*	**B2**

364. 9702_w16_MS_42 Q: 12

(a) (i) electron diffraction/electron microscope (allow other sensible suggestions) B1 [1]

(ii) photoelectric effect/Compton scattering (allow other sensible suggestions) B1 [1]

(b) (i) arrow clear from –0.54 eV to –3.40 eV B1 [1]

(ii) $E = hc/\lambda$ *or* $E = hf$ and $c = f\lambda$ C1

$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / [(3.40 - 0.54) \times 1.60 \times 10^{-19}] = 4.35 \times 10^{-7}$ m A1 [2]

(c) (i) wavelength associated with a particle M1
that is moving/has momentum/has speed/has velocity A1 [2]

(ii) $\lambda = h/mv$

$v = (6.63 \times 10^{-34}) / (9.11 \times 10^{-31} \times 4.35 \times 10^{-7})$ C1

$= 1.67 \times 10^{3}\,\text{m s}^{-1}$ A1 [2]

365. 9702_s20_MS_41 Q: 10

	Answer	Marks
(a)	• photon gives energy to electron (in an inner shell) **or** electron (in an inner shell) absorbs a photon • electron moves (from lower) to higher energy level • energy (of photon) is equal to difference in energy levels • electron de-excites giving off photon (of same energy) • photons emitted in all directions *Any four points, 1 mark each*	**B4**
(b)	(in light) photons gives energy to electrons in VB **or** (in light) electrons in VB absorb photons	**B1**
	electron crosses FB/jumps to CB	**B1**
	(positive) holes left/created in VB	**B1**
	low intensity: few electrons in CB/most electrons in VB **or** high intensity: more photons so more electrons in CB **or** electron-hole pairs are charge carriers	**B1**
	more charge carriers results in lower resistance	**B1**

366. 9702_s20_MS_42 Q: 11

	Answer	Marks
(a)	conduction band and valence band overlap	B1
	number (density) of charge carriers does not vary	B1
	increase in temperature gives rise to <u>increased</u> lattice vibrations	B1
	(lattice) vibrations hinder movement of charge carriers so resistance increases	B1
(b)	$mv = h / \lambda$	C1
	$v = (6.63 \times 10^{-34}) / [(2.6 \times 10^{-11}) \times (9.11 \times 10^{-31})]$ $(= 2.80 \times 10^{7}\ \text{m s}^{-1})$	C1
	$qV = ½mv^2$	C1
	$V = [9.11 \times 10^{-31} \times (2.80 \times 10^{7})^2] / [2 \times 1.60 \times 10^{-19}]$ $= 2.2 \times 10^{3}\ \text{V}$	A1

367. 9702_s20_MS_43 Q: 10

	Answer	Marks
(a)	• photon gives energy to electron (in an inner shell) **or** electron (in an inner shell) absorbs a photon • electron moves (from lower) to higher energy level • energy (of photon) is equal to difference in energy levels • electron de-excites giving off photon (of same energy) • photons emitted in all directions *Any four points, 1 mark each*	B4
(b)	(in light) photons gives energy to electrons in VB **or** (in light) electrons in VB absorb photons	B1
	electron crosses FB/jumps to CB	B1
	(positive) holes left/created in VB	B1
	low intensity: few electrons in CB/most electrons in VB **or** high intensity: more photons so more electrons in CB **or** electron-hole pairs are charge carriers	B1
	more charge carriers results in lower resistance	B1

368. 9702_m19_MS_42 Q: 11

	Answer	Marks
(a)	quantum / packet / discrete amount of <u>energy</u>	M1
	of electromagnetic radiation	A1
(b)	$E = hc / \lambda$	C1
	$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (540 \times 10^{-9})$	C1
	$= (3.68 \times 10^{-19}) / (1.6 \times 10^{-19})$ $= 2.3\ \text{eV}$	A1
(c)	Any 4 from: photon absorbed by electron in valence band (1) photon energy > energy of forbidden band (1) electron promoted to conduction band (1) hole left in valence band (1) more charge carriers so lower resistance (1)	B4

369. 9702_w19_MS_42 Q: 10

	Answer	Marks
(a)	(as temperature rises) electrons in valence band gain energy	B1
	electrons jump to conduction band	B1
	holes are left in the valence band	B1
	increased number (density) of charge carriers causes lower resistance	B1
(b)(i)	$V^- = V^+$	C1
	$1.50 / 1.20 = R_T / 1.76$	C1
	$R_T = 2.2$ (kΩ)	C1
	temperature = 14 °C	A1
(b)(ii)	(For LED to conduct,) V_{OUT} must be negative	B1
	$V^- > V^+$	B1
	R_T must be lower so temperature must be above **(b)(i)** value	B1

370. 9702_m18_MS_42 Q: 11

	Answer	Marks
(a)	no forbidden band / valence and conduction bands overlap	B1
	no change in number of charge carriers (as temperature rises)	B1
	increased lattice vibrations so resistance increases	B1
(b)	photons captured / absorbed by electrons in valence band	B1
	electrons promoted to conduction band	B1
	leaving holes in the valence band	B1
	more holes and / or electrons so resistance decreases	B1

371. 9702_s18_MS_41 Q: 11

	Answer	Marks
(a)(i)	packet/quantum/discrete amount of energy	M1
	of electromagnetic radiation	A1
(a)(ii)	(maximum) energy of emitted electrons is independent of intensity **or** no emission of electrons below the threshold frequency regardless of intensity **or** no emission of electrons when photon energy is less than work function (energy) regardless of intensity	B1
(b)	in darkness: conduction band empty so high resistance	B1
	in daylight: electrons in valence band absorb photons	B1
	in daylight: electrons 'jump' to conduction band	B1
	this leaves holes in valence band	B1
	more charge carriers in daylight so resistance decreases	B1

372. 9702_s18_MS_43 Q: 11

	Answer	Marks
(a)(i)	packet/quantum/discrete amount of energy	M1
	of electromagnetic radiation	A1
(a)(ii)	(maximum) energy of emitted electrons is independent of intensity **or** no emission of electrons below the threshold frequency regardless of intensity **or** no emission of electrons when photon energy is less than work function (energy) regardless of intensity	B1
(b)	in darkness: conduction band empty so high resistance	B1
	in daylight: electrons in valence band absorb photons	B1
	in daylight: electrons 'jump' to conduction band	B1
	this leaves holes in valence band	B1
	more charge carriers in daylight so resistance decreases	B1

373. 9702_w18_MS_41 Q: 10

	Answer	Marks
	Any five points from: • as temperature rises electrons gain energy • electrons enter conduction band • (positively charged) holes left in valence band • more charge carriers (so resistance decreases) • (as temperature rises,) lattice vibrations increase • effect of increase in number of electrons or holes or charge carriers outweighs effect of increased lattice vibrations (so resistance decreases)	B5

374. 9702_w18_MS_43 Q: 10

	Answer	Marks
	Any five points from: • as temperature rises electrons gain energy • electrons enter conduction band • (positively charged) holes left in valence band • more charge carriers (so resistance decreases) • (as temperature rises,) lattice vibrations increase • effect of increase in number of electrons or holes or charge carriers outweighs effect of increased lattice vibrations (so resistance decreases)	B5

375. 9702_m17_MS_42 Q: 11

	Answer	Marks
	any **five** from: • electrons need energy to enter conduction band (from valence band) • (positively-charged) holes are left in valence band • moving charge carriers / holes / electrons are current • (increase of temperature leads to) more (positive and negative) charge carriers / more holes / more electrons so more current • more charge carriers / holes / electrons gives rise to less resistance • (increase of temperature causes) greater (amplitude of) vibrations of atoms / ions / lattice • effect of more charge carriers/holes/electrons is greater than effect of greater vibrations (and so resistance decreases)	B5

376. 9702_w16_MS_41 Q: 11

in metal, conduction band overlaps valence band/no forbidden band/no band gap	B1	
as temperature rises, no increase in number of free electrons/charge carriers	B1	
as temperature rises, lattice vibrations increase	M1	
(lattice) vibrations restrict movement of electrons/charge carriers	M1	
(current decreases) so resistance increases	A1	[5]

377. 9702_w16_MS_43 Q: 11

in metal, conduction band overlaps valence band/no forbidden band/no band gap	B1	
as temperature rises, no increase in number of free electrons/charge carriers	B1	
as temperature rises, lattice vibrations increase	M1	
(lattice) vibrations restrict movement of electrons/charge carriers	M1	
(current decreases) so resistance increases	A1	[5]

378. 9702_m21_MS_42 Q: 11

	Answer	Marks
(a)(i)	electrons decelerate (on hitting target) so X-ray photons produced	**B1**
	range of decelerations	**B1**
	photon energy depends on (magnitude of) deceleration	**B1**
(a)(ii)	$eV = \frac{hc}{\lambda}$	**C1**
	$\lambda = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{1.6\times10^{-19}\times15000}$	**C1**
	$= 8.3\times10^{-11} m$	**A1**
	or $E = hf$ and $c = f\lambda$ and electron energy = eV *or* $E = hc/\lambda$ and electron energy = eV electron energy = $1.6\times10^{-19}\times15000$ $= 2.4\times10^{-15}$	**(C1)**
	$\lambda = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.4\times10^{-15}}$	**(C1)**
	$\lambda = 8.3\times10^{-11} m$	**(A1)**
(b)(i)	μ = – gradient *or* $\ln(I/I_o) = -\mu x$	**C1**
	(e.g. 2.08 / 10.0) = **0.21** cm^{-1}	**A1**

	Answer	Marks
(b)(ii)	$\ln(0.05) = -\mu x$	C1
	$x = \frac{\ln 0.05}{-\mu}$ *e.g.* $x = 14\,cm$	A1

379. 9702_s21_MS_41 Q: 11

	Answer	Marks
(a)	intensity: vary filament current/p.d. across filament	B1
	hardness: vary accelerating potential difference	B1
(b)(i)	$I = I_0 e^{-\mu x}$	C1
	$I_S = I_0 \exp(-0.92 \times 9.0)$ $= 2.5 \times 10^{-4}\ I_0$	A1
(b)(ii)	$I_C = [\exp(-0.92 \times 6.0) \times \exp(-2.9 \times 3.0)]\ I_0$	C1
	$= 6.7 \times 10^{-7}\ I_0$	A1
(c)	conclusion consistent with values in **(b)(i)** and **(b)(ii)** e.g. $I_S \gg I_C$ so good contrast	B1

380. 9702_s21_MS_43 Q: 11

	Answer	Marks
(a)	intensity: vary filament current/p.d. across filament	B1
	hardness: vary accelerating potential difference	B1
(b)(i)	$I = I_0 e^{-\mu x}$	C1
	$I_S = I_0 \exp(-0.92 \times 9.0)$ $= 2.5 \times 10^{-4}\ I_0$	A1
(b)(ii)	$I_C = [\exp(-0.92 \times 6.0) \times \exp(-2.9 \times 3.0)]\ I_0$	C1
	$= 6.7 \times 10^{-7}\ I_0$	A1
(c)	conclusion consistent with values in **(b)(i)** and **(b)(ii)** e.g. $I_S \gg I_C$ so good contrast	B1

381. 9702_w21_MS_41 Q: 11

	Answer	Marks
(a)(i)	ease with which edges can be distinguished	B1
(a)(ii)	difference in degrees of blackening	B1
(b)	$I = I_0 \exp(-\mu x)$	C1
	$0.12 = \exp(-\mu \times 2.3)$ $\ln 0.12 = -2.3 \times \mu$	C1
	$\mu = 0.92\ cm^{-1}$	A1
(c)	advantage: produces 3-dimensional image	B1
	disadvantage: (much) greater exposure to radiation	B1

382. 9702_w21_MS_43 Q: 11

	Answer	Marks
(a)(i)	ease with which edges can be distinguished	B1
(a)(ii)	difference in degrees of blackening	B1
(b)	$I = I_0 \exp(-\mu x)$	C1
	$0.12 = \exp(-\mu \times 2.3)$ $\ln 0.12 = -2.3 \times \mu$	C1
	$\mu = 0.92\ \text{cm}^{-1}$	A1
(c)	advantage: produces 3-dimensional image	B1
	disadvantage: (much) greater exposure to radiation	B1

383. 9702_m20_MS_42 Q: 11

	Answer	Marks
(a)	$eV = hf$ $f = 1.60 \times 10^{-19} \times 100\,000 / 6.63 \times 10^{-34}$	C1
	$= \mathbf{2.41 \times 10^{19}}$ Hz	A1
(b)	(aluminium filter) absorbs (most) low energy X-rays	B1
	Any 2 from • X-ray beam contains many wavelengths • so low energy X-rays are not absorbed in the body • low energy X-rays can can cause harm but do not contribute to the image	B2
(c)(i)	$I / I_o = e^{-\mu x}$ $e^{-0.23 \times 0.80} = 0.83$	C1
	17% absorbed	A1
(c)(ii)	bone is seen as lighter / muscle is seen as darker	B1
	either bone has a higher μ value so absorbs more *or* muscle has a lower μ value so transmits more	B1

384. 9702_m19_MS_42 Q: 9

	Answer	Marks
	X-rays (are used)	B1
	(object is) scanned in sections / slices	B1
	either: scans taken at many angles / directions *or* images of each section / slice are 2-dimensional	B1
	scans of many sections / slices are combined	B1
	(to give) 3-dimensional image (of whole structure)	B1

385. 9702_w19_MS_42 Q: 7

	Answer	Marks
	X-rays are used	B1
	section (of object) is scanned	B1
	scans/images taken at many angles/directions **or** images of each section are 2-dimensional	B1
	images of (many) sections are combined	B1
	(to give) 3-dimensional image of (whole) structure	B1

386. 9702_m18_MS_42 Q: 12

	Answer	Marks
(a)	Any 2 from: scattering of X-ray beam / no lead grid lack of collimation of beam / aperture large anode area large beam p.d. low / photon energy low / X-ray soft	B2
(b)(i)	$0.81 = (e^{-1.5 \times 0.32}) / (e^{-1.5 \times x})$	C1
	x = **1.8** mm	A1

	Answer	Marks
(b)(ii)	ratio/dB = 10 lg(0.81)	C1
	= (–) **0.92** dB	A1

387. 9702_s18_MS_41 Q: 12

	Answer	Marks
(a)(i)	$I = I_0 e^{-\mu x}$	C1
	$= I_0 \exp(-0.90 \times 2.8)$ $= 0.080 I_0$	A1
(a)(ii)	$I = I_0 \exp[(-0.90 \times 1.5) \times (-3.0 \times 1.3)]$	C1
	$= I_0 (0.259 \times 0.20)$ $= 0.0052 I_0$	A1
(b)(i)	difference in degrees of blackening	M1
	between structures	A1
(b)(ii)	large difference in intensities so good contrast	B1

388. 9702_s18_MS_42 Q: 11

	Answer	Marks
(a)	X-ray image(s) taken of one slice	M1
	(many images) taken from different angles	A1
	(computer) produces 2D image of slice	B1
	(this is) repeated for (many) slices	M1
	to build up a 3D image (of structure)	A1
(b)(i)	combining of images involves (very) large number of calculations	B1
(b)(ii)	CT scan consists of (very) many (single X-ray) images	B1

389. 9702_s18_MS_43 Q: 12

	Answer	Marks
(a)(i)	$I = I_0 e^{-\mu x}$	C1
	$= I_0 \exp(-0.90 \times 2.8)$ $= 0.080 I_0$	A1
(a)(ii)	$I = I_0 \exp[(-0.90 \times 1.5) \times (-3.0 \times 1.3)]$	C1
	$= I_0 (0.259 \times 0.20)$ $= 0.0052 I_0$	A1
(b)(i)	difference in degrees of blackening	M1
	between structures	A1
(b)(ii)	large difference in intensities so good contrast	B1

390. 9702_w18_MS_42 Q: 10

	Answer	Marks
(a)	$V_0 = \sqrt{2} \times V_{r.m.s.} = \sqrt{2} \times 9.9$ (= 14 V) **and** $\omega = 2\pi f = 2\pi \times 50$ (= 314 rad s^{-1})	C1
	$V = 14 \sin 314t$	A1
(b)	enables (resonating) nuclei to be located	B1
	resonant frequency depends on magnetic field strength	B1
	Any one from: • non-uniform field is (accurately) calibrated • (non-uniform) field may be varied to enable detection in different positions • unique (magnetic) field strength/frequency at each point	B1
(c)	$I = I_0 \exp(-\mu x)$	C1
	$I = I_0 [\exp(-\mu x)_{bone} \times \exp(-\mu x)_{soft\ tissue}]$ $I = I_0 [\exp(-2.9 \times 0.40) \times \exp(-0.92 \times 1.4)]$	C1
	$I / I_0 = 0.0865$	C1
	ratio / dB = 10 lg 0.0865 = –11 dB	A1

391. 9702_s17_MS_41 Q: 10

	Answer	Marks
(a)(i)	penetration of beam	M1
	greater hardness means greater penetration/shorter wavelength/higher frequency/higher photon energy	A1
(a)(ii)	greater accelerating potential difference **or** greater p.d. between anode and cathode	B1
(b)	$I = I_0 \exp(-\mu x)$ ratio = (exp {–1.5 × 2.9}) / (exp {–4.0 × 0.95}) (= exp {–0.55})	C1
	= 0.58	A1

392. 9702_s17_MS_43 Q: 10

	Answer	Marks
(a)(i)	penetration of beam	M1
	greater hardness means greater penetration/shorter wavelength/higher frequency/higher photon energy	A1
(a)(ii)	greater accelerating potential difference **or** greater p.d. between anode and cathode	B1
(b)	$I = I_0 \exp(-\mu x)$ ratio = (exp {–1.5 × 2.9}) / (exp {–4.0 × 0.95}) (= exp {–0.55})	C1
	= 0.58	A1

393. 9702_w17_MS_41 Q: 9

	Answer	Marks
(a)	image of one slice/section	(B1)
	images (of one slice) taken from different angles	(M1)
	to give 2D image (of one slice)	(A1)
	(repeated for) many slices	(M1)
	to build up 3D image (of whole body/structure)	(A1)
	Max. 4 marks total	4
(b)	evidence of subtraction of background (–26)	C1
	evidence of division by three	C1
	7 11 6 2	A1

394. 9702_w17_MS_43 Q: 9

	Answer	Marks
(a)	image of one slice/section	(B1)
	images (of one slice) taken from different angles	(M1)
	to give 2D image (of one slice)	(A1)
	(repeated for) many slices	(M1)
	to build up 3D image (of whole body/structure)	(A1)
	Max. 4 marks total	4
(b)	evidence of subtraction of background (–26)	C1
	evidence of division by three	C1
	$\begin{pmatrix} 7 & 11 \\ 6 & 2 \end{pmatrix}$	A1

395. 9702_m16_MS_42 Q: 12

(a) (i) the penetration of the beam B1 [1]

(ii) *either* decrease the accelerating voltage
or decrease voltage between cathode and anode B1 [1]

(b) advantage: image gives depth / image is 3D / final image can be viewed from any angle B1
disadvantage: greater exposure / more risk to health / more expensive / person must remain stationary B1 [2]

396. 9702_w16_MS_42 Q: 13

X-ray image of a (single) slice/cross-section (through the patient) M1
taken from different angles/rotating X-ray (beam) A1

computer is used to form/process/build up/store image B1
2D image (of the slice) B1

repeated for many/different (neighbouring) slices M1
to build up 3D image A1 [6]

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Q1.

7	(a)	$\lambda = h/p$ or $\lambda = h/mv$	M1	
		with λ, h and (or mv) p identified	A1	[2]
	(b)	$E = \frac{1}{2} mv^2$	C1	
		$= p^2/2m$ or $v = \sqrt{(2E/m)}$, <u>hence</u>	M1	
		$\lambda = h/\sqrt{(2mE)}$	A0	[2]
	(c)	$E = qV$	C1	
		$(0.4 \times 10^{-9})^2 \times 2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times V = (6.63 \times 10^{-34})^2$	C1	
		$V = 9.4$ V *(2 s.f. scores 2/3)*	A1	[3]
		Total		[7]

Q2.

7	(a)	'uniform' distribution	B1	[1]
	(b)	concentric rings	B1	[1]
	(c)	higher speed, more momentum	M1	
		$\lambda = h / p$	M1	
		so λ decreases and ring diameter decreases	A1	[3]

Q3.

5	(a)	(i)	packet/discrete quantity/quantum (of energy) of e.m. radiation	B1	[1]
		(ii)	either $E = (6.63 \times 10^{-34} \times 3 \times 10^{8})/(350 \times 10^{-9})$		
			or $E = (6.63 \times 10^{-34} \times 8.57 \times 10^{14})$	M1	
			$E = 5.68 \times 10^{-19}$ J	A0	[1]
		(iii)	0.5	B1	[1]
	(b)	(i)	energy of photon	M1	
			to cause emission of electron <u>from surface</u>		
			either with zero k.e *or* photon energy is minimum	A1	[2]
		(ii)	correct conversion eV → J or J → eV seen once	B1	
			photon energy must be greater than work function	C1	
			350 nm wavelength and potassium metal	A1	[3]

Q4.

7 (a) charge is quantised / discrete quantities — B1 [1]

(b) (i) parallel so that the electric field is uniform / constant — B1
horizontal so that *either* oil drop will not drift sideways
or field is vertical
or electric force is equal to weight — B1 [2]

(ii) $qE = mg$ — C1
$q \times 850 / (5.4 \times 10^{-3}) = 7.7 \times 10^{-15} \times 9.8$ — C1
$q = 4.8 \times 10^{-19}$ C and is negative — A1 [3]

(c) charge changes by 1.6×10^{-19} C between droplets / integral multiples — M1
so charge on electron is 1.6×10^{-19} C — A0 [1]

Q5.

8 (a) wave theory predicts any frequency would give rise to emission of electron — M1
if exposure time is sufficiently long — A1
photon has (specific value of) energy dependent on frequency — M1
emission if energy greater than threshold / work function / energy to remove electron from surface — A1 [4]

(b) photon is packet/quantum of energy — M1
of electromagnetic radiation — A1
(photon) energy = $h \times$ frequency — B1 [3]

every particle has an (associated) wavelength — B1
wavelength = h / p — M1
where p is the momentum (of the particle) — A1 [3]

Q6.

7 (a) for a wave, electron can 'collect' energy continuously — B1
for a wave, electron will always be emitted /
electron will be emitted at all frequencies..... — M1
after a sufficiently long delay — A1 [3]

(b) (i) *either* wavelength is longer than threshold wavelength
or frequency is below the threshold frequency
or photon energy is less than work function — B1 [1]

(ii) $hc / \lambda = \phi + E_{MAX}$ — C1
$(6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (240 \times 10^{-9}) = \phi + 4.44 \times 10^{-19}$ — C1
$\phi = 3.8 \times 10^{-19}$ J (*allow* 3.9×10^{-19} J) — A1 [3]

(c) (i) photon energy larger — M1
so (maximum) kinetic energy is larger — A1 [2]

(ii) fewer photons (per unit time) — M1
so (maximum) current is smaller — A1 [2]

Q7.

7	(a)	wavelength of wave associated with a particle that is moving	M1 A1	[2]
	(b) (i)	energy of electron = $850 \times 1.6 \times 10^{-19}$ $= 1.36 \times 10^{-16}$ J energy = $p^2 / 2m$ *or* $p = mv$ and $E_K = \frac{1}{2}mv^2$ momentum = $\sqrt{(1.36 \times 10^{-16} \times 2 \times 9.11 \times 10^{-31})}$ $= 1.6 \times 10^{-23}$ Ns	M1 M1 A0	[2]
	(ii)	$\lambda = h / p$ wavelength = $(6.63 \times 10^{-34}) / (1.6 \times 10^{-23})$ $= 4.1 \times 10^{-11}$ m	C1 A1	[2]
	(c)	diagram or description showing: electron beam in a vacuum incident on thin metal target / carbon film fluorescent screen pattern of concentric rings observed pattern similar to diffraction pattern observed with visible light	 B1 B1 B1 M1 A1	[5]

Q8.

8	(a)	packet/quantum/discrete amount of energy of electromagnetic radiation *(allow 1 mark for 'packet of electromagnetic radiation')* energy = Planck constant × frequency *(seen here or in **b**)*	M1 A1 B1	[3]
	(b)	each (coloured) line corresponds to one wavelength/frequency energy = Planck constant × frequency implies specific energy change between energy levels so discrete levels	B1 B1 A0	[2]

Q9.

6	(a)	oil drop charged by friction/beta source		B1	
		between parallel metal plates		B1	
		plates are horizontal	(1)		
		adjustable potential difference/field between plates		B1	
		until oil drop is stationary		B1	
		$mg = q \times V/d$		B1	
		symbols explained	(1)		
		oil drop viewed through microscope	(1)		
		m determined from terminal speed of drop (when p.d. is zero)	(1)		
		(*any two extras, 1 each*)		B2	[7]
	(b)	3.2×10^{-19} C		A1	[1]

Q10.

7	(a)	minimum energy to remove an electron from the metal/surface	B1	[1]
	(b)	gradient = 4.17×10^{-15} *(allow 4.1 → 4.3)*	C1	
		$h = 4.15 \times 10^{-15} \times 1.6 \times 10^{-19}$ *or* h = 4.1 to 4.3 × 10^{-15} eV s	A1	
		= 6.6×10^{-34} J s	A0	[2]
	(c)	graph: straight line parallel to given line		
		with intercept at any higher frequency	B1	
		intercept at between 6.9×10^{14} Hz and 7.1×10^{14} Hz	B1	[3]

Q11.

7	(a)	(i) lowest frequency of e.m. radiation	M1	
		giving rise to emission of electrons (from the surface)	A1	[2]
		(ii) $E = hf$	C1	
		threshold frequency = $(9.0 \times 10^{-19}) / (6.63 \times 10^{-34})$		
		= 1.4×10^{15} Hz	A1	[2]
	(b)	*either* 300 nm ≡ 10×10^{15} Hz (and 600 nm ≡ 5.0×10^{14} Hz)		
		or 300 nm ≡ 6.6×10^{-19} J (and 600 nm ≡ 3.3×10^{-19} J)		
		or zinc λ_0 = 340 nm, platinum λ_0 = 220 nm (and sodium λ_0 = 520 nm)	M1	
		emission from sodium and zinc	A1	[2]
	(c)	each photon has larger energy	M1	
		fewer photons per unit time	M1	
		fewer electrons emitted per unit time	A1	[3]

Q12.

7 (a) each wavelength is associated with a discrete change in energy M1
discrete energy change / difference implies discrete levels A1 [2]

(b) (i) 1. arrow from –0.54 eV to –0.85 eV, labelled L B1 [1]

2. arrow from –0.54 eV to –3.4 eV , labelled S B1 [1]
(two correct arrows, but only one label – allow 2 marks)
(two correct arrows, but no labels – allow 1 mark)

(ii) $E = hc / \lambda$ C1
$(3.4 - 0.54) \times 1.6 \times 10^{-19} = (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / \lambda$ C1
$\lambda = 4.35 \times 10^{-7}$ m A1 [3]

(c) –1.50 → –3.4 = 1.9 eV
–0.85 → –3.4 = 2.55 eV (allow 2.6 eV)
–0.54 → –3.4 = 2.86 eV (allow 2.9 eV)
3 correct, 2 marks with –1 mark for each additional energy
2 correct, 1 mark but no marks if any additional energy differences B2 [2]

Q13.

2 (a) $E = hc / \lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (486 \times 10^{-9})$ C1
$= 4.09 \times 10^{-19}$ J ...(allow 2 sf)..... A1 [2]

(b) energy level drawn at 4.09×10^{-19} J B1
transition 4.09×10^{-19} to zero clear B1
transition 4.09×10^{-19} to 3.03×10^{-19} clear ..... B1 [3]
(-1 for reversed arrows, -1 for extra level at 1.06)

Q14.

6 (a) packet/quantum of energy M1
energy = *hf* ..... A1 [2]

(b) e.g. threshold frequency outlined
max. k.e. independent of intensity
max. k.e. dependent on frequency (n.b. NOT proportional)
photoelectric current depends on intensity
instantaneous emission .... (*1 each, max 3*)..... B3 [3]

(c) (i) photons have same energy so E_{max} unchanged
intensity *OR* number of photons per unit time is halved,
so ½*n* *OR* *n* reduced B1
(allow 1 mark for statement that E_{max} unchanged and *n* reduced)

(ii) photons have higher energy so E_{max} increases..... B1
but fewer photons per unit time so *n* decreases ..... B1 [4]
(allow 1 mark for statement that E_{max} increases and n reduced)
(allow any argument based on increased efficiency)

Q15.

7 (a)	(i)	quantum/packet/discrete amount of energy	M1		
		electromagnetic mentioned	A1		[2]
	(ii)	max. k.e. corresponds to electron emitted from surface	B1		
		energy is required to bring electron to surface	B1		[2]
(b)		at higher frequency, fewer photons (per second) for same intensity	M1		
		so rate of emission decreases	A1		[2]
		(allow argument based on photoelectric efficiency)			

Q16.

7 (a)	e.g. 'instantaneous' emission (of electrons)			
	threshold frequency below which no emission			
	(max) <u>electron</u> energy dependent on frequency			
	(max) <u>electron</u> energy not dependent on intensity			
	rate of emission (of electrons) depends on intensity			
	(*any three sensible suggestions, 1 each*)	B3		[3]
(b) (i)	'packet' / quantum of energy	M1		
	of electromagnetic energy / radiation	A1		[2]
(ii)	discrete wavelengths mean photons have particular energies	M1		
	energy of photon determined by energy change of (orbital) electron	M1		
	so discrete energy levels	A0		[2]
(c) (i)	three energy changes shown correctly	B1		
	arrows 'pointing' in correct direction	B1		
	wavelengths correctly identified	B1		[3]
(ii)	chooses λ = 486 nm	C1		
	$\Delta E = hc / \lambda$	C1		
	$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (4.86 \times 10^{-9})$			
	$= 4.09 \times 10^{-19}$ J (*allow 2 s.f.*)	A1		[3]

Q17.

7 (a)	each line corresponds to a (specific) photon energy	B1		
	photon emitted when electron changes its energy level	B1		
	discrete energy changes so discrete levels	B1		[3]
(b) (i)	$E = hc / \lambda$ …(*allow ratio ideas*)	C1		
	$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (486 \times 10^{-9})$			
	$= 4.09 \times 10^{-19}$ J	A1		[2]
(ii)	four transitions to/from -5.45×10^{-19} J level	B1		
	all transitions shown from higher to lower energy (level)	B1		[2]
			[Total: 7]	

Q18.

7	(a)	(i)	e.g. electron / particle diffraction	B1	[1]
		(ii)	e.g. photoelectric effect	B1	[1]
	(b)	(i)	6	A1	[1]
		(ii)	change in energy = 4.57×10^{-19} J $\lambda = hc / E$ $= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (4.57 \times 10^{-19})$ $= 4.4 \times 10^{-7}$ m	C1 A1	[2]

Q19.

8	(a)		minimum frequency for electron to be emitted (from surface) of electromagnetic radiation / light / photons	M1 A1	[2]
	(b)		$E = hc / \lambda$ *or* $E = hf$ and $c = f\lambda$ *either* threshold wavelength $= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (5.8 \times 10^{-19})$ $= 340$ nm *or* energy of 340 nm photon $= 4.4 \times 10^{-19}$ J *or* threshold frequency $= 8.7 \times 10^{14}$ Hz *or* 450 nm $\rightarrow 6.7 \times 10^{14}$ Hz appropriate comment comparing wavelengths / energies / frequencies so no effect on photo-electric current	C1 A1 B1 B1	[4]

Q20.

7	(a)		each line represents photon of specific energy photon emitted as a result of energy change of electron specific energy changes so discrete levels	M1 M1 A1	[3]
	(b)	(i)	arrow from –0.85 eV level to –1.5 eV level	B1	[1]
		(ii)	$\Delta E = hc / \lambda$ $= (1.5 - 0.85) \times 1.6 \times 10^{-19}$ $= 1.04 \times 10^{-19}$ J $\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (1.04 \times 10^{-19})$ $= 1.9 \times 10^{-6}$ m	C1 C1 A1	[3]
	(c)		spectrum appears as continuous spectrum crossed by dark lines two dark lines electrons in gas absorb photons with energies equal to the excitation energies light photons re-emitted in all directions	B1 B1 M1 A1	[4]

Q21.

7 (a) (i) packet/quantum of energy — M1
of electromagnetic radiation — A1 [2]

(ii) minimum energy to cause emission of an electron (from surface) — B1 [1]

(b) (i) $hc/\lambda = \Phi + E_{max}$ — M1
c and *h* explained — A1 [2]

(ii) 1. *either* when $1/\lambda = 0$, $\Phi = -E_{max}$
or evidence of use of *x*-axis intercept from graph
or chooses point close to the line and substitutes values of $1/\lambda$ and E_{max} into $hc/\lambda = \Phi + E_{max}$ — C1
$\Phi = 4.0 \times 10^{-19}$ J (allow $\pm 0.2 \times 10^{-19}$ J) — A1 [2]

2. *either* gradient of graph is $1/hc$ — C1
gradient = $4.80 \times 10^{24} \rightarrow 5.06 \times 10^{24}$ — M1
h = 1/(gradient × 3.0×10^{8})
= 6.6×10^{-34} J s → 6.9×10^{-34} J s — A1
or chooses point close to the line and substitutes values of $1/\lambda$ and E_{max} into $hc/\lambda = \Phi + E_{max}$ — (C1)
values of $1/\lambda$ and E_{max} are correct within half a square — (M1)
h = 6.6×10^{-34} J s → 6.9×10^{-34} J s — (A1) [3]

(Allow full credit for the correct use of any appropriate method)
(Do not allow 'circular' calculations in ***part 2*** *that lead to the same value of Planck constant that was substituted in* ***part 1****)*

Q22.

8 (a) discrete quantity / packet / quantum of energy of electromagnetic radiation — B1
energy of photon = Planck constant × frequency — B1 [2]

(b) threshold frequency — (1)
rate of emission is proportional to intensity — (1)
max. kinetic energy of electron dependent on frequency — (1)
max. kinetic energy independent of intensity — (1)
(*any three, 1 each, max 3*) — B3 [3]

(c) *either* $E = hc/\lambda$ — *or* $hc/\lambda = eV$ — C1
λ = 450 nm to give — work function of *3.5 eV*
energy = 4.4×10^{-19} or 2.8 eV — to give λ = 355 nm — M1
2.8 eV < 3.5 eV so no emission — 355 nm < 450 nm so no — A1 [3]

or work function = 3.5 eV
threshold frequency = 8.45×10^{14} Hz — C1
450 nm = 6.67×10^{14} Hz — M1
6.67×10^{14} Hz < 8.45×10^{14} Hz — A1

Q23.

7	(a)	wavelength associated with a particle that is moving	M1 A1	[2]
	(b) (i)	kinetic energy = $1.6 \times 10^{-19} \times 4700$ $= 7.52 \times 10^{-16}$ J *either* energy = $p^2/2m$ *or* $E_K = \frac{1}{2}mv^2$ *and* $p = mv$ $p = \sqrt{(7.52 \times 10^{-16} \times 2 \times 9.1 \times 10^{-31})}$ $= 3.7 \times 10^{-23}$ Ns $\lambda = h/p$ $= (6.63 \times 10^{-34}) / (3.7 \times 10^{-23})$ $= 1.8 \times 10^{-11}$ m	C1 C1 C1 C1 A1	[5]
	(ii)	wavelength is about separation of atoms can be used in (electron) diffraction	B1 B1	[2]

Q24.

7	(a)	*either* if light passes through suitable film / cork dust etc. diffraction occurs and similar pattern observed *or* concentric circles are evidence of diffraction diffraction is a wave property	M1 A1 (M1) (A1)	[2]
	(b)	(speed increases so) momentum increases $\lambda = h/p$ so λ decreases hence radii decrease (*special case: wavelength decreases so radii decreases – scores 1/3*) *or* (speed increases so) energy increases $\lambda = h / \sqrt{(2Em)}$ so λ decreases hence radii decrease	M1 M1 A1 (B1) (M1) (A1)	[3]
	(c)	electron and proton have same (kinetic) energy *either* $E = p^2 / 2m$ *or* $p = \sqrt{(2Em)}$ ratio = $p_e / p_p = \sqrt{(m_e / m_p)}$ $= \sqrt{\{(9.1 \times 10^{-31}) / (1.67 \times 10^{-27})\}}$ $= 2.3 \times 10^{-2}$	C1 C1 C1 A1	[4]

Q25.

7 (a) (i) minimum photon energy B1
minimum energy to remove an electron (from the surface) B1 [2]

(ii) *either* maximum KE is photon energy – work function energy
or max KE when electron ejected from the surface B1
energies lower than max because energy required to bring electron to the surface B1 [2]

(b) (i) threshold frequency = 1.0×10^{15} Hz (*allow* $\pm 0.05 \times 10^{15}$) C1
work function energy = hf_0 C1
$= 6.63 \times 10^{-34} \times 1.0 \times 10^{15}$
$= 6.63 \times 10^{-19}$ J A1 [3]
(*allow alternative approaches based on use of co-ordinates of points on the line*)

(ii) sketch: straight line with same gradient M1
displaced to right A1 [2]

(iii) intensity determines number of photons arriving per unit time B1
intensity determines number of electrons per unit time (not energy) B1 [2]

Q26.

8 (a) discrete and equal amounts (of charge) B1 [1]
allow: discrete amounts of 1.6×10^{-19} *C/elementary charge/e*
integral multiples of 1.6×10^{-19} *C/elementary charge/e*

(b) weight = qV/d
$4.8 \times 10^{-14} = (q \times 680)/(7.0 \times 10^{-3})$ C1
$q = 4.9 \times 10^{-19}$ C A1 [2]

(c) elementary charge = 1.6×10^{-19} C (*allow* 1.6×10^{-19} C to 1.7×10^{-19} C) M0
either the values are (approximately) multiples of this
or it is a common factor C1
it is the highest common factor A1 [2]

Q27.

9 (a) e.g. no time delay between illumination and emission
max. (kinetic) energy of electron dependent on frequency
max. (kinetic) energy of electron independent of intensity
rate of emission of electrons dependent on/proportional to intensity
(*any three separate statements, one mark each, maximum 3*) B3 [3]

(b) (i) (photon) interaction with electron may be below surface B1
energy required to bring electron to surface B1 [2]

(ii) 1. threshold frequency = 5.8×10^{14} Hz A1 [1]

2. $\Phi = hf_0$ C1
$= 6.63 \times 10^{-34} \times 5.8 \times 10^{14}$
$= 3.84 \times 10^{-19}$ (J) C1
$= (3.84 \times 10^{-19})/(1.6 \times 10^{-19})$
$= 2.4$ eV A1 [3]

or

$hf = \Phi + E_{MAX}$ (C1)
chooses point on line and substitutes values E_{MAX}, f and h into equation with the units of the hf term converted from J to eV (C1)
$\Phi = 2.4$ eV (A1)

Q28.

8 (a) photon energy $= hc/\lambda$
$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(590 \times 10^{-9})$ C1
$= 3.37 \times 10^{-19}$ J C1

number $= (3.2 \times 10^{-3})/(3.37 \times 10^{-19})$
$= 9.5 \times 10^{15}$ (allow 9.4×10^{15}) A1 [3]

(b) (i) $p = h/\lambda$ C1
$= (6.63 \times 10^{-34})/(590 \times 10^{-9})$
$= 1.12 \times 10^{-27}$ kg m s^{-1} C1

total momentum $= 9.5 \times 10^{15} \times 1.12 \times 10^{-27}$
$= 1.06 \times 10^{-11}$ kg m s^{-1} A1 [3]

(ii) force $= 1.06 \times 10^{-11}$ N A1 [1]

Q29.

8 (a) photon 'absorbed' by electron B1
photon has energy equal to difference in energy of two energy levels B1
electron de-excites emitting photon (of same energy) in any direction B1 [3]

(b) (i) $E = hc/\lambda$ C1
$= (6.63 \times 10^{-34} \times 3 \times 10^{8})/(435 \times 10^{-9})$ C1
$= 4.57 \times 10^{-19}$ J (*allow 2 s.f.*) C1
$= (4.57 \times 10^{-19})/(1.6 \times 10^{-19})$ (eV)
$= 2.86$ eV (*allow 2 s.f.*) A1 [4]

(ii) arrow pointing in either direction between –3.41 eV and –0.55 eV B1 [1]

Q30.

7 (a) *either* charge exists in discrete and equal quantities
or multiples of elementary charge / e / 1.6×10^{-19} C — B1 [1]

(b) (i) force due to magnetic field must be upwards — B1
B-field into the plane of the paper — B1 [2]

(ii) sketch showing: deflection consistent with force in (b)(i) — B1
reasonable curve — B1 [2]

Q31.

8 (a) discrete amount / packet / quantum of energy — M1
of electromagnetic radiation / EM radiation — A1 [2]

(b) (i) $E = hc/\lambda$
$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (570 \times 10^{-9}) = 3.49 \times 10^{-19}$ J — A1 [1]

(ii) 1. number $= (2.7 \times 10^{-3}) / (3.5 \times 10^{-19})$ — C1
$= 7.7 \times 10^{15}$ — A1 [2]

2. momentum of photon $= h/\lambda$ — C1
$= (6.63 \times 10^{-34}) / (570 \times 10^{-9})$
$= 1.16 \times 10^{-27}$ kgms^{-1} — C1

change in momentum $= 1.16 \times 10^{-27} \times 7.7 \times 10^{15}$
$= 8.96 \times 10^{-12}$ kgm s^{-1} — A1 [3]

(*allow $E = pc$ route to 9×10^{-12}*)

(c) pressure = (change in momentum per second) / area — C1
$= (8.96 \times 10^{-12}) / (1.3 \times 10^{-5})$
$= 6.9 \times 10^{-7}$ Pa — A1 [2]

Q32.

1 (a) charge is quantised/enabled electron charge to be measured — B1 **[1]**

(b) all are (approximately) n x (1.6×10^{-19} C) — M1
so $e = 1.6 \times 10^{-19}$ C (allow 2 sig. fig. only — A1 **[2]**
summing charges and dividing ten, without explanation scores 1/2
Total **[3]**