22. Quantum Physics

22.2 Photoelectric effect

Paper 4

Marking Scheme

Q1.

(a)	photoelectric effect	**B1**
(b)(i)	$E = hf$	**C1**
	work function $= 6.63 \times 10^{-34} \times 8.8 \times 10^{14}$ $= 5.8 \times 10^{-19}$ J	**A1**
(b)(ii)	$hf = \Phi + ½ mv_{MAX}^2$	**C1**
	$6.63 \times 10^{-34} \times 11 \times 10^{14} = (5.8 \times 10^{-19}) + (½ \times 9.11 \times 10^{-31} \times v_{MAX}^2)$	**C1**
	$v_{MAX} = 5.7 \times 10^5$ m s^{-1}	**A1**
(c)	E_{MAX} shown as zero from $f = 8.0$ to 8.8 and non-zero from $f = 8.8$ to 11	**B1**
	all non-zero E_{MAX} shown as a single straight line with a positive gradient	**B1**
	line passing through (11, 1.45)	**B1**

Q2.

(b)(i)	photoelectric effect	**B1**
(b)(ii)	• electron needs a minimum energy to escape **or** electron emitted if energy in packet is enough • energy must be absorbed in packets that are related to frequency • intensity relates to number of packets (not to energy in packet) • electron absorbs only a single whole packet *Any three points, 1 mark each*	**B3**
(c)(i)	Planck constant	**B1**
(c)(ii)	– work function (energy)	**B1**

Q3.

(b)(i)	photoelectric effect	**B1**
(b)(ii)	• there is a frequency below which no electrons are emitted **or** threshold frequency = 5.4×10^{14} Hz • work function of the metal = 3.6×10^{-19} J (or 2.2 eV) • E_{MAX} increases (linearly) with (increasing) frequency • gradient of the line is the Planck constant **or** gradient of the line is 6.7×10^{-34} J s *Any three bullet points, 1 mark each*	**B3**
(c)(i)	different threshold frequency	**B1**
	(line has) same gradient but different intercept	**B1**
(c)(ii)	photons have same energy	**B1**
	line unchanged	**B1**

Q4.

(a)	photon energy (to remove electron)	**B1**
	minimum energy to remove electron **or** energy to remove electron from surface **or** energy to remove electron with zero kinetic energy	**B1**
(b)(ii)	$hf = \Phi + E_{MAX}$	**C1**
	$\Phi = (1.36 \times 10^{15} \times 6.63 \times 10^{-34}) - (3.09 \times 10^{-19})$ $= 5.93 \times 10^{-19}$ J	**A1**
(c)(i)	greater photon energy (and same work function)	**M1**
	so maximum kinetic energy is increased	**A1**
(c)(ii)	(greater photon energy and same power so) lower number of photons (per unit time)	**M1**
	(each electron absorbs one photon) so lower rate of emission	**A1**

Q5.

(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)(ii)	E_{MAX} = photon energy – work function	**C1**
	work function = 5.0 – 1.4 = 3.6 eV	**A1**

Q6.

(b)	line with negative gradient from $\lambda = \frac{1}{3}\lambda_0$ to $\lambda = \lambda_0$	**B1**
	line passing through (λ_0, 0)	**B1**
	curve with negative gradient of decreasing magnitude passing through ($\frac{1}{2}\lambda_0$, E_{MAX}) and ($\frac{1}{3}\lambda_0$, $2E_{MAX}$)	**B1**

Q7.

(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**

Q8.

(a)	any two points from: • (maximum) kinetic energy of electrons is independent of intensity • maximum kinetic energy of electrons depends on frequency • no time delay (between illumination and emission)	**B2**
(b)(i)	(for E_{MAX} = 0,) $1/\lambda_0 = 1.93 \times 10^6$ (m^{-1})	**C1**
	$f_0 = 3.00 \times 10^8 \times 1.93 \times 10^6$ $= 5.8 \times 10^{14}$ Hz	**A1**
(b)(ii)	$hc/\lambda = \Phi + E_{MAX}$	**C1**
	hc = gradient	**C1**
	gradient = e.g. $[(0.40 - 0.20) \times 1.60 \times 10^{-19}] / [(2.25 - 2.09) \times 10^6]$ (*working needed*) $(= 2.0 \times 10^{-25})$	**M1**
	$h = (2.0 \times 10^{-25}) / (3.00 \times 10^8) = 6.7 \times 10^{-34}$ J s (*both working and answer needed*)	**A1**
(c)	straight line with same gradient as the original	**B1**
	straight line with x-axis intercept greater than 1.93×10^6 m^{-1}	**B1**

Q9.

(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)(ii)	photon energy must be greater than work function (energy)	**B1**
	so sodium and calcium	**B1**

Q10.

(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**
	$\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = (7.1 - 5.5) \times 10^{-19}$	**C1**
	$v = 5.9 \times 10^5$ m s^{-1}	**A1**
(b)(ii)	energy is required to bring electron to the surface	**B1**
(c)	no change / decreases increases / decreases	**B4**

Q11.

(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**

Q12.

(a)	emission of electron	**B1**
	when electromagnetic radiation incident (on surface)	**B1**
(b)(iii)	sodium: yes zinc: no	**B1**

Q13.

(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**