

1. (i) Visible (light) B1
- (ii) work function = $1.9 \times 1.6 \times 10^{-19}$ M1
 work function = 3.04×10^{-19} (J) $\approx 3.0 \times 10^{-19}$ (J) A0
- (iii) 1. $E = hf / E = \frac{hc}{\lambda}$ C1
 $E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{5.1 \times 10^{-7}}$
 $E = 3.9 \times 10^{-19}$ (J) A1
2. $hf = \phi + KE_{(\max)} / hf = \phi + \frac{1}{2} mv^2$
 (Allow $E = \phi + \frac{1}{2} mv^2$ if E is qualified in (iii)1.) C1
 $3.9 \times 10^{-19} = 3.0 \times 10^{-19} + KE_{(\max)} / 3.9 \times 10^{-19} = 3.04 \times 10^{-19} + KE_{(\max)}$ C1
 $KE = 9.0 \times 10^{-20}$ (J) / $KE = 8.6 \times 10^{-20}$ (J) (Possible ecf) A1
- (iv) No change (to maximum KE of electron) B1
 Each photon has same energy (but there are fewer photons) B1
- (v) number of photons = $\frac{80 \times 10^{-3}}{3.9 \times 10^{-19}}$ ($\approx 2.05 \times 10^{17}$) (Possible ecf) C1
 number of electrons = $0.07 \times \frac{80 \times 10^{-3}}{3.9 \times 10^{-19}}$
 number of electrons = 1.44×10^{16} (s^{-1}) $\approx 1.4 \times 10^{16}$ (s^{-1}) A1

[11]

2. (i) The minimum frequency needed to free an electron
 (from the surface of a metal) B1
- (ii)1 Line extended intersects (the f axis at) this value / At this frequency, $E_k = 0$ B1
- (ii)2 ($\phi =$) $h \times 5.0 \times 10^{14}$ / ($\phi =$) $6.63 \times 10^{-34} \times 5.0 \times 10^{14}$ C1
 work function energy = 3.3×10^{-19} J A1
- (iii)1 1 The gradient / slope of the line is the same B1
 The gradient is equal to h / independent of the metal B1
- (iii)2 The line is shifted to the right B1
 The threshold frequency is greater (AW) B1

[8]

3. Any six from: (Allow AW)
1. Photoelectric effect is the removal of electrons (from metals) when exposed to light / u.v. / e.m. radiation / photons B1
 2. Surface electrons are involved / electrons released from the surface B1
 3. A single photon interacts with a single electron B1
 4. Energy is conserved (in the interaction) B1
 5. Energy of photon = hf or $\frac{hc}{\lambda}$ B1
 6. Reference to Einstein's photoelectric equation: $hf = \phi + KE_{(max)}$ C1
 7. photon energy = work function (energy) + (maximum) KE (of electron) A1
 8. PE effect takes place / electron(s) released when $hf > \phi$ / $hf = \phi$ / frequency is greater / equal to threshold frequency B1
 9. The (maximum) KE of electron is independent of intensity when electrons are emitted B1
 10. Intensity increases the rate / number of electrons when emission occurs B1
 11. PE effect does not take place / no electrons emitted when $hf < \phi$ / frequency < threshold frequency B1
 12. Intensity has 'no effect' when there is no emission of electrons B1
- QWC for 'organisation' B1

[7]

4. (a) (i) $E = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 6.3 \times 10^{-7}$
mark is for correct substitution into formula M1
- $= 3.16 \times 10^{-19}$ (J)
min of 2 sig figs; allow 3.1 for $h = 6.6 \times 10^{-34}$ A1
- (ii) $1.0 \times 10^{-3} / 3.2 \times 10^{-19} (= 3.1 \times 10^{15})$
accept 3×10^{15} ; the mark is for the expression B1
- (iii) energy levels explanation: electrons have discrete energies in atom/AW
QWC mark B1
- each photon produced by electron moving between levels
good diagram can score marks B1
- photon energy equal to energy difference between levels
allow $E_1 - E_2 = hf$ or similar B1
- electron loses energy/making transition in correct direction B1

- (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
allow tolerance e.g. $\pm 10^\circ$
- B1
- (ii) $I = 0.2 ne; = 0.2 \times 3.2 \times 10^{15} \times 1.6 \times 10^{-19}$
max 2 marks if forget 0.2 factor
- C2
- $= 1.0(24) \times 10^{-4}$ (A) or 0.10 mA (9.6×10^{-5} if using 3×10^{15})
0.51 mA (0.48) if forget 0.2 factor
- A1
- (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
award mark for any sensible comment; see examples given
- B1
- [14]**
5. (a) (i) paths spread out after passing through a gap or around an obstacle/AW
- B1
- (ii) wavelength of electrons
allow electrons behave as waves/AW
- M1
- must be comparable/of the order of magnitude of the atomic spacing
allow must be about 10^{-10} m
- A1
- (b) $\lambda = h/mv$
mark for selecting formula
- C1
- $v = 6.6(3) \times 10^{-34} / 9.1(1) \times 10^{-31} \times 1.2 \times 10^{-10}$
correct manipulation and subs. shown
- M1
- $= 6.0$ or 6.1×10^6 (m s^{-1})
give all 3 marks for answers to 3 figs or more: i.e. 6.04, 6.06 or 6.07
- A1

- (c) (i) $eV = \frac{1}{2}mv^2$
mark for algebraic equation C1
- $V = mv^2/2e = 9.1 \times 10^{-31} \times (6.0 \times 10^6)^2/2 \times 1.6 \times 10^{-19}$
mark for correct substitution C1
- $= 1.0(2) \times 10^2$ (V)
give 1 mark max for k.e. = $1.6(4) \times 10^{-17}$ J
using 6.1 gives 104 (V) A1
- (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
award mark if answer indicates this idea B1

[10]

6. (a) (i) line spacing $d = 1/(300 \times 1000)$ ($= 3.3 \times 10^{-6}$ (m))
look for clear reasoning to award mark B1
- (ii) $\sin \theta = \lambda/d$
 $= 6.3 \times 10^{-7}/3.3 \times 10^{-6} = 0.19$
 $\theta = 11$ degrees
rounding error of 0.2 here gives 11.9°
 11.9° gets 2 marks C1
C1
A1
- (iii) spots can be seen where $n = d \sin \theta/\lambda$
 maximum n when $\sin \theta = 1$ (giving $n = 5.3$) so $n = 5$ can be seen
 thus 5 spots on either side of straight through + straight through = 11
accept basic idea of orders for first mark
N.B. calculation not necessary B1
B1
B1
- (b) (i) $\epsilon = hc/\lambda = 6.6 \times 10^{-34} \times 3.0 \times 10^8/6.3 \times 10^{-7}$
 $= 3.14 \times 10^{-19}$ (J) C1
A1
- (ii) $5.0 \times 10^{-4}/3.14 \times 10^{-19}$
 $= 1.6 \times 10^{15}$
accept 3.2×10^{-19} (J)
ecf from b(i)1 C1
A1

[11]

7. (i) (Minimum) energy needed to free an electron /an electron to escape
(from the metal surface) B1
- (ii) speed of light / 3×10^8 (m s⁻¹) / c B1
- (iii) 1. $hf = \phi + KE_{(\max)}$ (Allow any subject) C1
 $KE_{\max} = 2.8 - 1.1 = 1.7$ (eV) C1
 $KE_{\max} = 1.7 \times 1.6 \times 10^{-19}$
 $KE_{\max} = 2.7 \times 10^{-19}$ (J) A1
 2. $\frac{1}{2}mv^2 = 2.7 \times 10^{-19}$ (Possible ecf) C1

$$v = \sqrt{\frac{2 \times 2.7 \times 10^{-19}}{9.1 \times 10^{-31}}}$$
 $v = 7.7 \times 10^5$ (m s⁻¹) A1
- (iv) No change (because the energy of the photon remains the same) B1

[8]

8. *Electromagnetic waves - Any two from:* B1 × 2
- EM wave / light behave like ‘particle’/ photon / quantum of energy
 - $E = hf$ / $E = hc/\lambda$
 - E is the energy of photon and f is the frequency (of EM waves) / λ is the wavelength
- Moving electrons - Any four from:* B1 × 4
- Moving / travelling particle / electron behaves like a wave
 - Mention of the de Broglie (equation)
 - $\lambda = \frac{h}{mv}$
 - λ is the wavelength of particle/electron, m is the mass (of particle) and v is speed
 - Electrons can be diffracted (Can score on diagram)
 - Electrons travelling through matter /graphite (show diffraction effects) (Can score on diagram if not scored in 8 above)
 - Electrons diffract because their wavelength is comparable to the size of atoms /gap between atoms (Do not allow ‘particles in place of atoms)
- QWC** Spelling, punctuation and grammar B1
 Organisation B1

[8]