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. $hf = \phi + KE_{(max)}$ / $hf = \phi + ½\ mv^2$
(Allow $E = \phi + ½\ mv^2$ 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

$$\text{number of electrons} = 0.07 \times \frac{80 \times 10^{-3}}{3.9 \times 10^{-19}}$$

number of electrons = 1.44×10^{16} (s^{-1}) $\approx 1.4 \times 10^{16}$ (s^{-1}) A1

[11]

2. (i) The <u>minimum</u> 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

B1

energy per photon is higher (so fewer needed to produce one mW)

B1

(b) (i) vertical arrow up approximately through **X**

allow *tolerance e.g. ± 10°*

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) × 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) $\varepsilon = hc/\lambda = 6.6 \times 10^{-34} \times 3.0 \times 10^8/6.3 \times 10^{-7}$
$= 3.14 \times 10^{-19}$ (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. ½ $mv^2 = 2.7 \times 10^{-19}$ (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 <u>two</u> from:* B1 × 2

1. EM wave / light behave like ‘particle’/ photon / quantum of energy
2. $E = hf$ / $E = hc/\lambda$
3. E is the energy of <u>photon</u> and f is the frequency (of EM waves) / λ is the wavelength

Moving electrons - Any <u>four</u> from: B1 × 4

4. Moving / travelling particle / electron behaves like a wave
5. Mention of the <u>de</u> <u>Broglie</u> (equation)
6. $\lambda = \frac{h}{mv}$
7. λ is the wavelength of <u>particle/electron</u>, m is the mass (of particle) and v is speed
8. Electrons can be diffracted (Can score on diagram)
9. Electrons travelling through matter /graphite (show diffraction effects) (Can score on diagram if not scored in 8 above)
10. 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]