1. (i) Visible (light)

(ii) work function = \(1.9 \times 1.6 \times 10^{-19}\)  
work function = \(3.04 \times 10^{-19}(J) \approx 3.0 \times 10^{-19}(J)\)

(iii) 1. \(E = \frac{hf}{\lambda} = \frac{hc}{\lambda}\)
\[E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{5.1 \times 10^{-7}}\]
\[E = 3.9 \times 10^{-19}(J)\]  
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.)
\[3.9 \times 10^{-19} = 3.0 \times 10^{-19} + KE_{(max)} / 3.9 \times 10^{-19} = 3.04 \times 10^{-19} + KE_{(max)}\]
\[KE = 9.0 \times 10^{-20}(J) / KE = 8.6 \times 10^{-20}(J)\] (Possible ecf)

(iv) No change (to maximum KE of electron)
Each photon has same energy (but there are fewer photons)

(v) number of photons = \(\frac{80 \times 10^{-3}}{3.9 \times 10^{-19}} = 2.05 \times 10^{17}\) (Possible ecf)
number of electrons = \(0.07 \times \frac{80 \times 10^{-3}}{3.9 \times 10^{-19}}\)
number of electrons = \(1.44 \times 10^{16}(s^{-1}) \approx 1.4 \times 10^{16}(s^{-1})\)

2. (i) The minimum frequency needed to free an electron
(from the surface of a metal)

(ii)1 Line extended intersects (the \(f\) axis at) this value / At this frequency, \(E_k = 0\)

(ii)2 (\(\phi = \frac{h}{5 \times 10^{14}}\) / \(\phi = \frac{6.63 \times 10^{-34} \times 5 \times 10^{14}}{A}\))
work function energy = \(3.3 \times 10^{-19}\)

(iii)1 The gradient / slope of the line is the same
The gradient is equal to \(h\) / independent of the metal

(iii)2 The line is shifted to the right
The threshold frequency is greater (\(AW\)
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

2. Surface electrons are involved / electrons released from the surface

3. A single photon interacts with a single electron

4. Energy is conserved (in the interaction)

5. Energy of photon = $hf$ or $\frac{hc}{\lambda}$

6. Reference to Einstein’s photoelectric equation: $hf = \Phi + KE_{(\text{max})}$

7. Photon energy = work function (energy) + (maximum) KE (of electron)

8. PE effect takes place / electron(s) released when $hf > \Phi$ / $hf = \Phi$ / frequency is greater / equal to threshold frequency

9. The (maximum) KE of electron is independent of intensity when electrons are emitted

10. Intensity increases the rate / number of electrons when emission occurs

11. PE effect does not take place / no electrons emitted when $hf < \Phi$ / frequency < threshold frequency

12. Intensity has ‘no effect’ when there is no emission of electrons

QWC for ‘organisation’

4. (a) (i) $E = \frac{hc}{\lambda} = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 6.3 \times 10^{-7}$

mark is for correct substitution into formula

$= 3.16 \times 10^{-19}$ (J)

min of 2 sig figs; allow 3.1 for $h = 6.6 \times 10^{-34}$

(ii) $1.0 \times 10^{-3}/3(2) \times 10^{-19} (= 3.1 \times 10^{15})$

accept $3 \times 10^{15}$; the mark is for the expression

(iii) energy levels explanation: electrons have discrete energies in atom/AW

QWC mark

each photon produced by electron moving between levels

good diagram can score marks

photon energy equal to energy difference between levels

allow $E_1 - E_2 = hf$ or similar

electron loses energy/making transition in correct direction
(iv) blue light has a higher frequency/shorter wavelength than red light
energy per photon is higher (so fewer needed to produce one mW)

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

  \[ I = 0.2 \times 3.2 \times 10^{15} \times 1.6 \times 10^{-19} \]

  \[ = 1.0(24) \times 10^{-4} \text{ (A)} \text{ or } 0.10 \text{ mA (9.6} \times 10^{-5} \text{ if using } 3 \times 10^{15}) \]

  \[
  0.51 \text{ mA (0.48) if forget 0.2 factor}
  \]

(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

5. (a) (i) paths spread out after passing through a gap or around an obstacle/AW

(ii) wavelength of electrons

  allow electrons behave as waves/AW

  must be comparable/of the order of magnitude of the atomic spacing

  allow must be about \(10^{-10} \text{ m}\)

(b) \(\lambda = h/mv\)

  mark for selecting formula

  \[
  v = 6.6(3) \times 10^{-34} / 9.1(1) \times 10^{-31} \times 1.2 \times 10^{-10} 
  \]

  correct manipulation and subs. shown

  \[
  = 6.0 \text{ or } 6.1 \times 10^{6} \text{ (m s}^{-1})
  \]

  give all 3 marks for answers to 3 figs or more: i.e. 6.04, 6.06 or 6.07
(c) (i) $eV = \frac{1}{2}mv^2$

*mark for algebraic equation*

$$V = \frac{mv^2}{2e} = 9.1 \times 10^{-31} \times (6.0 \times 10^6)^2 / 2 \times 1.6 \times 10^{-19}$$

*mark for correct substitution*

$$= 1.0(2) \times 10^2 \text{ (V)}$$

*give 1 mark max for k.e. = 1.6(4) \times 10^{-17} \text{ J}*

*using 6.1 gives 104 (V)*

(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*

6. (a) (i) line spacing $d = 1/(300 \times 1000) (= 3.3 \times 10^{-6} \text{ (m)})$

*look for clear reasoning to award mark*

(ii) $\sin \theta = \frac{\lambda}{d} = \frac{6.3 \times 10^{-7}}{3.3 \times 10^{-6}} = 0.19$

$\theta = 11 \text{ degrees}$

*rounding error of 0.2 here gives 11.9°*

11.9° gets 2 marks

(iii) spots can be seen where $n = \frac{d \sin \theta}{\lambda}$

*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*

(b) (i) $\varepsilon = \frac{hc}{\lambda} = 6.6 \times 10^{-34} \times 3.0 \times 10^8 / 6.3 \times 10^{-7}$

$$= 3.14 \times 10^{-19} \text{ (J)}$$

*accept 3.2 \times 10^{-19} \text{ (J)}*

*ecf from b(i)*

(ii) $5.0 \times 10^{-4} / 3.14 \times 10^{-19}$

$$= 1.6 \times 10^{15}$$

*accept 3.2 \times 10^{-19} \text{ (J)}*

*ecf from b(i)*
7. (i) Minimum energy needed to free an electron / an electron to escape (from the metal surface) B1
(ii) speed of light / $3 \times 10^8$ (m s$^{-1}$) / c B1
(iii) 1. $hf = \phi + KE_{\text{max}}$ (Allow any subject) C1
   $KE_{\text{max}} = 2.8 - 1.1 = 1.7$ (eV) C1
   $KE_{\text{max}} = 1.7 \times 1.6 \times 10^{-19}$
   $KE_{\text{max}} = 2.7 \times 10^{-19}$ (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. Electromagnetic waves - Any two from: B1 $\times$ 2
1. EM wave / light behaves like ‘particle’ / photon / quantum of energy
2. $E = hf / E = hc/\lambda$
3. $E$ is the energy of photon and $f$ is the frequency (of EM waves) / $\lambda$ is the wavelength
   Moving electrons - Any four from: B1 $\times$ 4
4. Moving / travelling particle / electron behaves like a wave
5. Mention of the de Broglie (equation)
6. $\lambda = \frac{h}{mv}$
7. $\lambda$ is the wavelength of particle/electron, $m$ 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