Question	Answer	Marks
1 (a)	A photon is a quantum of energy of an electromagnetic wave.	1
1 (b)	A single photon interacts with a single surface electron. Energy is conserved in this interaction between a photon and an electron. An electron is only removed when the energy of the photon is equal or greater than the work function of the metal. (Or, an electron is only removed when the frequency of the electromagnetic radiation is equal or greater than the threshold frequency of the metal.) Any one from: Reference to Einstein's photoelectric equation $hf = \phi + KE_{max}$. Intensity has no effect on the KE of the emitted photoelectrons (when the frequency is greater than the threshold frequency).	1 1 1 1
1 (c) (i)	$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{6.3 \times 10^{-7}}$ $E = 3.16 \times 10^{-19}$ J $E = \frac{3.16 \times 10^{-19}}{1.60 \times 10^{-19}} = 1.97$ eV	1 1 1
1 (c) (ii)	number of photons per second = $\frac{2.0 \times 10^{-3}}{3.16 \times 10^{-19}}$ number of photons per second = $6.3 \times 10^{15}\ s^{-1}$	1 1
2 (a) (i)	$\frac{hc}{\lambda} = \phi + KE_{max}$ $\phi = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{220 \times 10^{-9}} - \frac{1}{2} \times 9.11 \times 10^{-31} \times (1.2 \times 10^{6})^{2}$ $\phi = 2.48 \times 10^{-19}$ J	1 2 1
2 (a) (ii)	$f_0 = \frac{\phi}{h} = \frac{2.48 \times 10^{-19}}{6.63 \times 10^{-34}}$ $f_0 = 3.74 \times 10^{14}$ Hz	1 1
2 (b)	The maximum KE of an electron is given by the equation $KE_{max} = \frac{hc}{\lambda} - \phi$. This shows that the maximum KE is independent of intensity.	1 1
3 (a)	$KE_{max} = hf - \phi$ (Einstein's photoelectric equation) The maximum kinetic energy KE_{max} is not directly proportional to the frequency f (and hence the graph does not pass through the origin).	1 1
3 (b)	threshold frequency $f_0 = 3.5 \times 10^{14}$ Hz from the graph $\phi = hf_0 = 6.63 \times 10^{-34} \times 3.5 \times 10^{14} = 2.3 \times 10^{-19}$ J	1 1
3 (c)	The gradient of the graph is equal to the Planck constant h. Hence there is no change to the gradient of the line graph. The intercept with the f-axis is equal to the threshold frequency and this will increase because of the greater work function. Hence the line graph will move to the right (but will have the same gradient).	1 1 1 1
4 (a)	A particle moving through space has a wavelength λ given by the de Broglie equation $\lambda = \frac{h}{p}$, where h is the Planck constant and p is the momentum of the particle.	1
4 (b)	$\frac{1}{2}mv^2 = eV$ or $\frac{1}{2}\frac{p^2}{m} = eV$ $p = \sqrt{2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 200}$ $p = 7.64 \times 10^{-24}$ kg m s^{-1} $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{7.64 \times 10^{-24}}$ $\lambda = 8.7 \times 10^{-11}$ m	1 1 1 1 1

Question	Answer	Marks
4 (c)	The separation or distance between the atoms of a solid must be similar to the de Broglie wavelength of the electrons.	1
5 (a) (i)	the minimum energy ϕ required for an electron to escape from metal surface	2
5 (a) (ii)	a photon with less than the threshold frequency f_0 cannot cause electron emission so work function = *h* (threshold frequency)	1 1
5 (a) (iii)	$\phi = \frac{hc}{\lambda}$ $\phi = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{550 \times 10^{-9}}$ $\phi = 3.6 \times 10^{-19}$ J	 1 1
5 (b) (i)	$KE_{max} = hf - \phi$ or $hf = \phi + KE_{max}$ $hf = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{440 \times 10^{-9}} = 4.5 \times 10^{-19}$ J $\frac{1}{2}mv^2 = 9 \times 10^{-20}$ giving $v^2 = \frac{1.8 \times 10^{-19}}{9.1 \times 10^{-31}}$ $v = 4.45 \times 10^{5}$ m s^{-1}	1 1 1
5 (b) (ii)	$h = \frac{\lambda}{mv} = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 4.5 \times 10^{5}}$ $\lambda = 1.6 \times 10^{-9}$ m	1 1
6 (a)	Any two from: No charge, travels at the speed of light in a vacuum, energy $\propto$ frequency, etc.	 2
6 (b) (i)	The energy *E* of the photon is given by $E = \frac{hc}{\lambda}$. Hence, $E \propto \frac{1}{\lambda}$ because *h* and *c* are constants.	1 1
6 (b) (ii)	The gradient is equal to *h c*, where *h* is the Planck constant and *c* is the speed of light in a vacuum. This is because $E = hc \times \frac{1}{\lambda}$.	1 1
6 (c) (i)	energy of photon = $\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{5.5 \times 10^{-7}}$ energy of photon = 3.616×10^{-19} J number of photons per second = $\frac{6.3 \times 10^{7} \times 4\pi \times (7.0 \times 10^{8})^2}{3.616 \times 10^{-19}}$ number of photons per second = 1.07×10^{45} s^{-1}	1 1 1 1
6 (c) (ii)	intensity $\propto \frac{1}{r^2}$ intensity = $6.3 \times 10^{7} \times \left(\frac{7.0 \times 10^{8}}{1.5 \times 10^{11}}\right)^2$ intensity = 1.37×10^{3} W m^{-2}	1 1 1
7 (a)	The energy of a photon is given by: energy = *h* × frequency The de Broglie wavelength is given by: wavelength = $\frac{h}{\text{momentum}}$	1 1
7 (b)	The removal of surface electrons from a metal using electromagnetic radiation.	1
7 (c)	The minimum frequency of the incident electromagnetic radiation that will emit electrons from the surface of a metal.	1
7 (d)	$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{4.0 \times 10^{-7}} = 4.973 \times 10^{-19}$ J $E = \frac{4.973 \times 10^{-19}}{1.60 \times 10^{-19}} = 3.11$ eV $hf = \phi + KE_{max}$ $\phi = 3.11 - 1.6 = 1.5$ eV	1 1 1 1

Question	Answer	Marks
8 (a)	$hf = \phi + E_k$; therefore a graph of E_k against f will give a gradient equal to h. h = gradient = $\frac{(4.0 - 2.0) \times 10^{-19}}{(9.0 - 6.0) \times 10^{14}}$ = 6.7×10^{-34} J s	1 1 1
8 (b)	The kinetic energy of the photoelectrons is independent of intensity. Hence the graph remains the same.	1 1