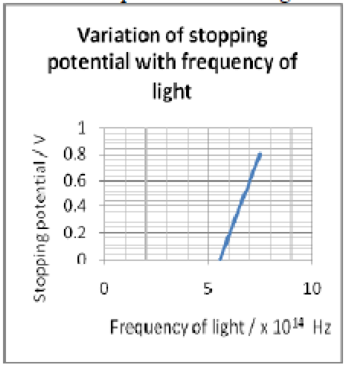
The Photoelectric Effect – ANSWERS:

Q	Evidence	Evidence contributing to Achievement	Evidence contributing to Achievement with Merit	Evidence contributing to Achievement with Excellence
1(a)	$E = hf$ $E = 6.63 \times 10^{-34} \times 6.16 \times 10^{14}$ $E = 4.08408 \times 10^{-19}$ J	Correct answer. A2		
1(b)	No electrons are emitted / nothing would happen / Photons energy is changed to heat.	Correct statement. A1		
1(c)	$E_K = 0.35 \times 1.6 \times 10^{-19} = 5.6 \times 10^{-20}$ J $\phi = 4.08 \times 10^{-19} - 5.6 \times 10^{-20}$ $= 3.52 \times 10^{-19}$ J $f = \frac{\phi}{h}$ $= \frac{3.52 \times 10^{-19}}{6.63 \times 10^{-34}}$ $= 5.309 \times 10^{14}$ $=$ **5.3×10^{14} Hz**	*Correct calculation of E_K in joules.* A2	*Correct f consistent with incorrect E_K / correct work function.* M2	Correct answer. E2
1(d)	Graph line is parallel to the one shown but displaced to the right.	Correct graph line. A1		
1(e)	In brighter light there will be more photons hitting the metal per second. As each photon releases an electron, more electrons will be released each second, hence greater current. OR – the light frequency is now below the threshold frequency and so no electrons are released regardless of brightness.	*ONE correct and relevant statement:* Brighter light means more photons / more photons so greater current/ brighter light means more electrons **AND** more current. A1	Link made between brighter light having more **photons**, and more photons emitting more electrons. **OR** below f_o no electrons as not enough energy per photon to release electrons regardless of brightness. M1	*In addition candidate refers to rate of photons hitting / rate of electrons being released*
1(f)	The cut-off voltage is a measure of the maximum kinetic energy of the emitted electrons in electron volts. Although there are more photons and hence more electrons released, each photon will release an electron with the same maximum KE. The cut-off voltage will therefore remain the same.	*ONE correct and relevant statement:* cut-off voltage depends on max KE of electrons / max KE of electrons stays the same even though brightness changes / no change in cut-off voltage. A1	Link made between cut-off voltage depending on KE of electrons, and brightness not affecting KE of electrons. M1	Explanation is clear, concise and accurate – clear understanding of voltage as energy per charge or as a measure of electron max KE. E1

1(g)	According to the wave model, the brighter the light the greater the energy it carries. This suggests that a brighter light should release electrons with greater KE. In practice the energy of released electrons is independent of the brightness of the light. According to the wave model, frequency is independent of the energy of the wave and so all frequencies should release electrons with the same amount of energy. In practice, the energy of released electrons depends on the frequency of the light. As energy in a light wave is delivered in a smooth continuous way, it should take some time for electrons to be emitted. In practice electrons are emitted instantaneously.	*ONE behaviour that is not predicted by the wave model is given.* A1	TWO behaviours that are not predicted by the wave model are given. For ONE, the predicted behaviour is given. M1	

TWO (a)	Red light photons have low frequency so low energy, therefore they don't have enough energy to release electrons. Violet light has higher frequency so higher energy photons, they give the electrons enough energy to leave the surface of the sodium OR Red light frequency is less than the threshold frequency, so electrons do not have enough energy to escape. Violet photons have more energy, so they have enough to let electrons escape. OR The electrons in sodium have a work function which is a minimum amount of energy required for them to leave the surface. The photons of light must provide this energy or else the electron can't escape. Red light photons have an energy less that the work function, and violet light photons have a greater energy than the work function.	[1] Indicates understanding that there is a minimum energy from photons / quanta of radiation causes emission of electrons OR energy of red photons is less than that of violet. OR idea that there is a minimum frequency for electron emission and red light is below the threshold frequency.	[1] [Links energy of light to frequency or wavelength OR good understanding of photons] AND [Compares violet light energy and red light energy OR links to increasing wavelength] AND Enough/not enough energy to [cause electrons to be emitted OR overcome work function] Has to have link between energy and emission.	

(b)	As the intensity increases, more photons are hitting the target each second, causing more electron emissions per second and hence more in the circuit and a larger current. The light is still violet, so the frequency and **energy** of the photons is not changed, (so each electron gets the same energy as before). Therefore the speed of the emitted electrons will not be changed. (This explanation needs - speed of electron, not just energy of the electron, AND energy of the photons, not just frequency)	[1] One effect described with no incorrect effects OR Two effects described with one incorrect effect OR One effect described and explained (with incorrect effect/s)	[1] One effect described and explained OR all three effects described but not explained. To get merit there must be no incorrect effects (e.g. electrons are faster)	[1] Complete answer. All correct plus has clearly linked to increased (or decreased) intensity

(c)(i)	At the stopping potential, $eV = E_K$ $E_K = 1.6 \times 10^{-19} \times 0.8 = 1.28 \times 10^{-19}$ $= 1.3 \times 10^{-19}$ J		Correct answer with working.	
(ii)	$f_{violet} = \frac{v}{\lambda} = \frac{3 \times 10^8}{4.0 \times 10^{-7}} = 7.5 \times 10^{14}\ Hz$ $hf = \phi + E_K$ $\phi = hf - E_K$ $= 7.5 \times 10^{14} \times 6.63 \times 10^{-34} - 1.28 \times 10^{-19}$ $= 3.6925 \times 10^{-19}\ J$ (from c(i)) $f_{threshold} = \frac{\phi}{h} = \frac{3.6925 \times 10^{-19}}{6.63 \times 10^{-34}} = 5.56938 \times 10^{14}$ $= 5.6 \times 10^{14}\ Hz$ Graph connects points (5.6,0) and (7.5,0.8) which is the point for violet light. 	Correct calculation of frequency of violet light and correct shape of graph (straight line with positive slope that cuts the x-axis) Note: Frequency of violet light could be found in c(i) OR Correct work function calculated.	Correct calculation of the threshold frequency.	Correct threshold frequency with correct working and correct graph.

Question Three Evidence Statement

1(a)	Electrons in the metal surface will absorb the energy of incident photons that have energy above the cut off frequency for the metal. Because these electrons have too much energy to remain bound inside the atom they are emitted and are able to travel to the collector plate.	Idea of electrons absorbing energy from the photons and being emitted.	Full explanation.	
(b)	If the incident photons have a higher frequency they have greater energy ($E = hf$). The energy required by an electron to be released is the same regardless of the energy of the photon, so the greater the energy of the photon the greater the energy left over to give the electron kinetic energy. All this kinetic energy has to be changed to electric potential energy before the electron reaches the collector. As $E_P = qV$, a greater voltage is needed to change the kinetic energy of the electron to electric potential energy.	Higher frequency incident photons linked to greater energy emitted electrons.	Higher voltage linked to more negative charge on collector which is linked to ability to successfully repel electrons with more energy.	Correct explanation in terms of electric fields.
(c)	It is the minimum frequency photon that has enough energy to release an electron. or It is the frequency at which the photon energy is equal to the work function energy.	Correct answer.		
(d)	$hf = \phi + E_K$ The kinetic energy of the electron is all changed to E_P, and $E_P = eV$. So the equation becomes $hf = \phi + eV \Rightarrow V = \frac{h}{e}f - \frac{\phi}{e}$ Therefore the intercept on the voltage axis is $\frac{\phi}{e}$. $\Rightarrow \phi = 1.60 \times 10^{-19} \times 2.28 = 3.65 \times 10^{-19}$ J OR: The frequency that gives a stopping voltage of zero is when the photon energy exactly matches the work function energy and so the electron is released with zero kinetic energy. $hf = \phi + E_K$ so if $E_K = 0$, $\phi = hf_o$. From the graph $f_o = 6.63 \times 10^{-34} \times 5.6 \times 10^{14}$ $= 3.7128 \times 10^{-19} = 3.71 \times 10^{-19}$ J	Recognition that ϕ is found from the voltage intercept. Recognition that $\phi = hf_o$ provides replacement evidence for (d)	Graph is correctly related to the photoelectric equation Correct answer	Correct answer including an explanation for why $E_P = eV$. Correct answer including an explanation for why $\phi = hf_o$.