

Question	Answer	Marks	Guidance
1 (a)	the minimum energy required to remove an electron from the surface of a metal	1	'State what is meant by' can usually be answered by giving a definition.
1 (b) (i)	Graph features: See EA 3.1.1 below <ul style="list-style-type: none"> • correct axis labels and units • suitable scales • at least 5 points plotted correctly • best fit line 	4	Graph features: See EA 3.1.1 below <ul style="list-style-type: none"> • correct axis labels and units • suitable scales • at least 5 points plotted correctly • best fit line.
1 (b) (ii)	the graph is a straight line which does not pass through the origin $E_K = hf - \phi$ is an equation of the same form as that of the general straight line, $y = mx + c$ $m = h$, and $c = -\phi$	1 1 1	Because the line is of the same form as a general straight line, direct comparison with $y = mx + c$ will satisfy what this part requires.
1 (b) (iii)	$h = \text{gradient of graph}$ $= \frac{3.7 \times 10^{-19} \text{ J}}{(10 - 4.3) \times 10^{14} \text{ Hz}}$ $= 6.5 \times 10^{-34} \text{ J s}$ at the intercept f_0 on the f-axis $E_K = 0$, so work function $\phi = hf_0$ intercept value, $f_0 = 4.3 \times 10^{14} \text{ Hz}$ and $\phi = 6.5 \times 10^{-34} \times 4.3 \times 10^{14}$ $= 2.8 \times 10^{-19} \text{ J}$	1 1 1 1 1	By comparison with m above. Show fully how you have worked out the gradient. It may help to include the units. The correct unit is an essential part of this answer. f_0 is the threshold frequency for photoemission to occur. Just read off the graph! This solution uses the value of h found earlier, but you could get away with using the value from the Data Booklet ($6.63 \times 10^{-34} \text{ J s}$).
1 (c)	if the test does not provide supporting evidence, the prediction is incorrect so the theory is incorrect and must be changed	1 1	This is the 'experimental method' of verifying a scientific theory. Some theories (such as parts of Einstein's work on gravity) are still impossible to verify experimentally.
2 (a)	Name: work function Definition: the minimum energy required to remove an electron from the surface of a metal	1 1	This is a characteristic of each metal surface. Remember to include 'minimum' and 'surface' in the definition.

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2 (b)	Relevant points include: <ul style="list-style-type: none"> incident photon has fixed energy photon loses all its energy in a single interaction electron can lose various amounts of energy in reaching surface of metal electrons have a maximum kinetic energy = (photon energy) – work function 	3	Incident photons all have the same energy because the light is monochromatic. An incident photon then transfers all its energy to an electron in the metal. An electron below the surface will have to do work, losing energy, in order to reach the surface. On leaving the surface the electron loses a further quantity of energy, the work function. So the maximum energy a photoelectron can have is that given to it by the photon, less the work function. Electrons coming from deeper inside the metal will be emitted with less energy than those originally at the surface.
2 (c) (i)	$\phi = hf - E_K$ $= (6.63 \times 10^{-34} \times 1.8 \times 10^{15}) - 4.2 \times 10^{-19}$ $= 7.73 \times 10^{-19} \text{ J}$	1 1 1	The starting equation could be rearranged from Data Booklet if you can't remember it. Keep 3 significant figures in the working because you need the energy value from (i) when working out the answer to (ii).
2 (c) (ii)	$f_0 = \frac{7.73 \times 10^{-19}}{6.63 \times 10^{-34}}$ $= 1.2 \times 10^{15} \text{ Hz}$	1 1	
3 (a)	minimum frequency for emission = 4.0×10^{14} Hz (from intercept on f -axis) $\lambda = \frac{c}{f} = \frac{3.00 \times 10^8}{4.0 \times 10^{14}}$ $= 7.5 \times 10^{-7} \text{ m}$	1 1 1	The maximum wavelength corresponds to the minimum frequency for emission, which can be read directly off the graph. Use of $c = f\lambda$ then leads to the answer.
3 (b) (i)	the line would be parallel to the original line, but the intercept on the f -axis would be at 8.0×10^{14} Hz	1	If you compare $E_K = hf - \phi$ with the straight line equation $y = mx + c$, it should be clear that h is the gradient (m).
3 (b) (ii)	<ul style="list-style-type: none"> the gradient of the line is the Planck constant, h, so it is unchanged 1 the intersection with the f-axis is doubled because $hf = \phi$ when the photoelectrons have zero kinetic energy 	1 1	h is a constant, so the gradient is unchanged. When $E_K = 0$, we are at the threshold frequency, where $hf = \phi$. When the work function ϕ is doubled, so is the threshold frequency.

[illegible]

Question	Answer	Marks	Guidance
7 (a)	electron diffraction (or interference)	1	Until electron diffraction had been discovered, diffraction and interference were only associated with waves.
7 (b)	$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 5.00 \times 10^5}$ $= 1.46 \times 10^{-9} \text{ m}$	1 1	It is preferable to keep all 3 significant figures in this answer, as you may need the value in (c).
7 (c)	mass of muon = $207 \times 9.11 \times 10^{-31}$ (= $1.89 \times 10^{-28} \text{ kg}$) speed $v = \frac{h}{m\lambda} = \frac{6.63 \times 10^{-34}}{1.89 \times 10^{-28} \times 1.46 \times 10^{-9}}$ $= 2.4 \times 10^3 \text{ m s}^{-1}$	1 1 1	An alternative approach: Since λ is the same, the muons must have the same momentum as the electrons: $m_e v_e = m_\mu v_\mu$ So $v_\mu = \frac{m_e v_e}{m_\mu} = \frac{5.00 \times 10^5}{207}$ $= 2.4 \times 10^3 \text{ m s}^{-1}$
7 (d)	Relevant points include: <ul style="list-style-type: none"> • both experience the same increase in energy (or have same work done on them) • wavelength is inversely proportional to momentum • gain in momentum is different for the muons and electrons • the smaller mass has the largest acceleration (or gain in speed) 	2	A more mathematical approach: Each will gain the same kinetic energy, so let $mv^2 = \text{constant } (k)$. Now $v = \frac{h}{m\lambda}$ Error! Bookmark not defined. $\sqrt{\frac{k}{m}}$, leading to $\lambda = \frac{h}{mv}$ $= \frac{h}{m} \sqrt{\frac{m}{k}}$, and as both h and k are constants, λ is proportional to $\frac{1}{m^{\frac{1}{2}}}$ Thus a particle with larger mass must have a smaller de Broglie wavelength. (Actually λ is $1.0 \times 10^{-10} \text{ m}$ for the muons in this example.)