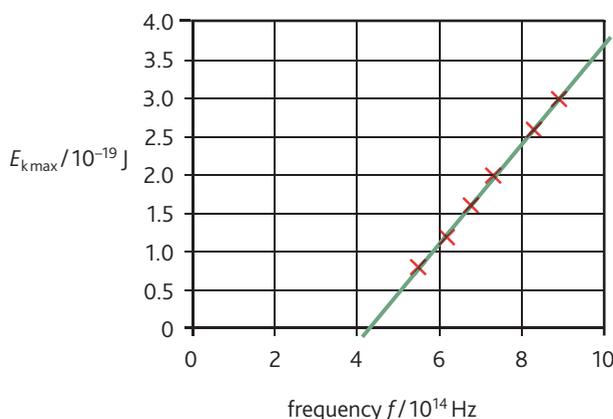


Answers to examination-style questions

**Answers**

**Marks Examiner's tips**

- 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.
- (b) (i) *Graph features:* See EA 3.1.1 below **4** These are standard expectations in graph questions. Make sure that you label the axes properly with quantities and units and that you mark the points clearly. A scale will be acceptable if your graph fills more than half of the area of the graph paper.
- correct axis labels and units
  - suitable scales
  - at least 5 points plotted correctly
  - best fit line
- (ii) the graph is a straight line which does not pass through the origin **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.
- $E_K = hf - \phi$  is an equation of the same form as that of the general straight line,  $y = mx + c$  **1**
- $m = h$ , and  $c = -\phi$  **1**
- (iii)  $h =$  gradient of graph **1** By comparison with  $m$  above.
- $$= \frac{3.7 \times 10^{-19} \text{ (J)}}{(10 - 4.3) \times 10^{14} \text{ (Hz)}}$$
- $$= 6.5 \times 10^{-34} \text{ J s}$$
- 1** Show fully how you have worked out the gradient. It may help to include the units.
- 1** The correct unit is an essential part of this answer.
- at the intercept  $f_0$  on the  $f$ -axis  $E_K = 0$ , **1**  $f_0$  is the threshold frequency for photoemission to occur.
- so work function  $\phi = hf_0$  **1** Just read off the graph!
- intercept value,  $f_0 = 4.3 \times 10^{14} \text{ Hz}$  **1** This solution uses the value of  $h$  found earlier, but you could get away with using the value from the Data Booklet ( $6.63 \times 10^{-34} \text{ J s}$ ).
- and  $\phi = 6.5 \times 10^{-34} \times 4.3 \times 10^{14}$  **1**
- $$= 2.8 \times 10^{-19} \text{ J}$$
- (c) if the test does not provide supporting evidence, the prediction is incorrect so the theory is incorrect and must be changed **1** This is the 'experimental method' of verifying a scientific theory.
- 1** Some theories (such as parts of Einstein's work on gravity) are still impossible to verify experimentally.



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2 (a) <i>Name:</i> work function	1	This is a characteristic of each metal surface.
<i>Definition:</i> the minimum energy required to remove an electron from the surface of a metal	1	Remember to include 'minimum' and 'surface' in the definition.
(b) <i>Relevant points include:</i> <ul style="list-style-type: none"> <li>incident photon has fixed energy</li> <li>photon loses all its energy in a single interaction</li> <li>electron can lose various amounts of energy in reaching surface of metal</li> <li>electrons have a maximum kinetic energy = (photon energy) – work function</li> </ul>	3	Incident photons all have the same energy because the light is monochromatic. An incident photon then transfers <b>all</b> 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, <b>less</b> the work function. Electrons coming from deeper inside the metal will be emitted with less energy than those originally at the surface.
(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).
(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 $= 4.0 \times 10^{14} \text{ Hz}$ (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 <b>maximum wavelength</b> corresponds to the <b>minimum frequency</b> for emission, which can be read directly off the graph. Use of $c = f\lambda$ then leads to the answer.
(b) (i) the line would be parallel to the original line, but the intercept on the $f$ -axis would be at $8.0 \times 10^{14} \text{ Hz}$	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 ( $m$ ). $h$ 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 $\phi$ is doubled, so is the threshold frequency.
(ii) <ul style="list-style-type: none"> <li>the gradient of the line is the Planck constant, <math>h</math>, so it is unchanged</li> <li>the intersection with the <math>f</math>-axis is doubled because <math>hf = \phi</math> when the photoelectrons have zero kinetic energy</li> </ul>	1 1	

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<p>4 (a) there must be sufficient distance between collisions for the electrons to gain enough energy for the required excitations to occur or the vapour must not completely absorb the electrons</p>	1	In crossing the tube, the electrons gain kinetic energy. The larger the distance they travel between collisions, the greater the energy they acquire. Collisions with atoms can then give the atoms the necessary (relatively high) energy needed for ultraviolet emission to occur on de-excitation of the mercury atoms.
<p>(b) <i>Relevant points include:</i></p> <ul style="list-style-type: none"> <li>the mercury vapour emits ultraviolet radiation</li> <li>the ultraviolet radiation excites the atoms of the coating</li> <li>the coating then emits electromagnetic radiation of longer wavelengths (or lower frequencies)</li> <li>some of which is in the visible region</li> </ul>	3	Both ionisation and excitation are involved in the operation of the fluorescent tube. In (b) the processes involved are excitation of the coating by incident short $\lambda$ radiation and its de-excitation accompanied by the emission of longer $\lambda$ radiation. Any of these 3 points would gain full marks.
<p>5 (a) frequency <math>f = \frac{E_1 - E_2}{h}</math>  <math>= \frac{-0.26 \times 10^{-18} - (-0.59 \times 10^{-18})}{6.63 \times 10^{-34}}</math>  <math>= 5.0 \times 10^{14}</math> Hz</p>	1  1	This answer uses a rearrangement of the equation for the energy of an emitted photon, $E_1 - E_2 = hf$ .
<p>(b) from <math>n = 3</math> to <math>n = 2</math></p>	1	A longer wavelength is required, so the frequency of the photon must be lower and the energy difference producing it must be smaller. On the diagram, only $n = 3$ to $n = 2$ ( $0.29 \times 10^{-18}$ J) will satisfy this.
<p>6 (a) electrons behave both as waves and as particles <i>Wave behaviour:</i> they can be diffracted, or show interference effects <i>Particle behaviour:</i> can be deflected in electric or magnetic fields, or make collisions with atoms</p>	1  1  1	Electrons are usually thought of as particles, and the collisions they make with atoms produce effects similar to those given by other colliding particles. But the particle-like behaviour of waves (as shown by the photoelectric effect) raised the possibility of a similar dual behaviour by electrons. The discovery of electron diffraction showed that it did, in fact, happen.
<p>(b) (i) From <math>\lambda = \frac{h}{mv}</math>, speed <math>v = \frac{h}{m\lambda}</math>  <math>= \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.3 \times 10^{-10}}</math>  <math>= 5.6 \times 10^6</math> m s<sup>-1</sup></p>	1  1	The answer comes from a rearrangement of the de Broglie wavelength equation. Like the Planck constant $h$ , the electron rest mass $m$ is given in the Data Booklet.

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(ii) $m = \frac{h}{\lambda v} = \frac{6.63 \times 10^{-34}}{8.6 \times 10^{-14} \times 5.6 \times 10^6}$ $= 1.4 \times 10^{-27} \text{ kg}$	1 1	A further rearrangement of the de Broglie equation gives this result.
7 (a) electron diffraction (or interference)	1	Until electron diffraction had been discovered, diffraction and interference were only associated with waves.
(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).
(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	<i>An alternative approach:</i> Since $\lambda$ is the same, the muons must have the same momentum as the electrons: $m_e v_e = m_\mu v_\mu$ So $v_\mu = \frac{m_e v_e}{m_\mu} = \frac{5.00 \times 10^5}{207}$ $= 2.4 \times 10^3 \text{ m s}^{-1}$
(d) <i>Relevant points include:</i> <ul style="list-style-type: none"> <li>• both experience the same increase in energy (or have same work done on them)</li> <li>• wavelength is inversely proportional to momentum</li> <li>• gain in momentum is different for the muons and electrons</li> <li>• the smaller mass has the largest acceleration (or gain in speed)</li> </ul>	2	<i>A more mathematical approach:</i> Each will gain the same kinetic energy, so let $mv^2 = \text{constant } (k)$ . Now $v = \sqrt{\frac{k}{m}}$ , leading to $\lambda = \frac{h}{mv} = \frac{h}{m} \sqrt{\frac{m}{k}}$ , and as both $h$ and $k$ are constants, $\lambda$ is proportional to $m^{-\frac{1}{2}}$ . Thus a particle with larger mass must have a smaller de Broglie wavelength. (Actually $\lambda$ is $1.0 \times 10^{-10} \text{ m}$ for the muons in this example.)