Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		Tube removes ambient light **AW** (As) it can be difficult to judge when the LED starts to emit light (due to ambient light) / (so) low-level light from LED is more visible	B1 B1	**Examiner's Comments** There were many successful responses for this question. Many responses were given 2 marks because they explained why a cardboard tube improves the accuracy of each measurement due to removing light from the surroundings, which enabled the light from the LED to be observed when it was first emitted.
	b		Calculates gradient using at least half the graph *eV=hf* **Or** *h=gradient* × 1.6×10^{-19} *h* = 3.5×10^{-34} J s	B1 C1 A1	Minimum range of x value 3.5×10^{14} Range 3.4 to 3.5 × 10^{-34} J s 2sf **Examiner's Comments** There was some variability in performance with this question, but many responses achieved 3 marks for a correct calculation and value for the Planck constant using data from the graph. The most common reason for responses being given 0 marks were for an error in their gradient calculations for either taking readings from less than half the graph, or for not including the correct power for frequency 10^{14}. Some candidates did correctly calculate the gradient from the graph, but then did not select and apply eV=hf to calculate a value of the Planck constant.
	c		$\frac{6.63 \times 10^{-34} - 3.5 \times 10^{-34}}{6.63 \times 10^{-34}}$ 47%	C1 A1	**ECF** from (b) **Allow** range 47% to 49% **Not** 50% from 52.8% if calculated from $3.5 \times 10^{-34} / 6.63 \times 10^{-34}$ **Examiner's Comments** Candidates did not perform well on this question as many candidates were given 0 marks. The most common reason for candidates not

					achieving marks was for not calculating a difference between the calculated and accepted value for the Planck constant with many candidates carrying out the calculation calculated value/accepted value x 100%. **Assessment for learning** Please refer to page 36 of the Practical Skills Handbook for information on correct methodology on calculating percentage difference between calculated and accepted values.
	d		energy of one photon of blue light = $6.63 \times 10^{-34} \times 6.38 \times 10^{14}$ (=4.23×10^{-19} J) number emitted in 1s = $\frac{1 \times 10^{-3}}{(6.63 \times 10^{-34} \times 6.38 \times 10^{14})}$ / $1 \times 10^{-3} \div 4.23 \times 10^{-19}$ 2.4×10^{15} photons of blue light which is less than for red light (3.3×10^{15})/the student is incorrect	C1 C1 A1	Calcn using v=fλ and E=hc/λ **Examiner's Comments** Most candidates were given 1 mark for correctly calculating the energy of one photon of blue light by selecting and applying E=hf. Some candidates correctly converted the power of the LED to calculate the number of blue photons emitted in 1 second by using and applying P=E/t. Where candidates did not achieve any further marks, thi was for selecting an incorrect equation and not applying P=E/t.
			Total	**10**	
2	a		Maximum kinetic energy of the emitted/ejected (photo)electron	B1	**Accept** released/escaped **Ignore** KE **Examiner's Comments** This should have been a straightforward definition of the maximum kinetic energy of electrons when they are emitted from the surface of a metal but many candidates were not given the mark as their definitions lacked specific scientific language.
	b		Electron(s) (on the metal surface) absorbs photon(s)/one to one interaction with a photon	B1 B1 B1	**Allow** absorbs energy from EM radiation

			Electrons are emitted (from the metal surface) The leaf becomes less (negatively) charged (and the leaf falls)		**Allow** electroscope/metal plate **Not** from the gold leaf **Allow** loses (negative) charge **Not** reference to positive charge **<u>Examiner's Comments</u>** Most candidates were given at least 1 mark for this question for the explanation that when electromagnetic radiation is incident on the metal plate electrons are emitted. Some candidates were then given a further mark for explaining that the gold leaf fell due to losing negative charge but there were a significant number of responses that referred to positive charge and that as the leaf was losing negative charge it became positively charged. While candidates may not have observed a demonstration of a gold leaf electroscope, the question assessed their understanding and explanation of the photoelectric effect and that is only the removal of excess electrons when there is a one-to-one interaction with a photon.
	c		Energy of a photon is smaller than the work function (for the metal) The electron does not receive enough energy to be emitted	B1 B1	There were not many successful responses for this question and many responses were given 0 marks. These responses did not explain the reason for the leaf not falling in relation to photon energy and the work function, and hence that the electron does not receive enough energy to be emitted. Typical responses that were not given marks were for a description of threshold frequency as the minimum frequency required for electrons to be emitted and/or for simple stating that the leaf does not fall as electrons are not emitted. While these descriptions were valid, candidates had not applied E_p=hf and Φ=hf_o to explain that the energy of the photon was less than the work function required for electrons to be emitted.
			Total	**6**	
3			**B**	1	**<u>Examiner's Comments</u>** Candidates performed well on this

					question with many correctly relating an increase in intensity of radiation to an increase in the rate of emission of electrons.
			Total	**1**	
4	a		Calculation in eV: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19}$ (J) $E_{\text{light photon}} = 3.9 \times 10^{-19} / 1.6 \times 10^{-19}$ $= 2.44$ (eV) Number of photons = ($E_{\text{x-ray photon}}/E_{\text{light photon}}$) × efficiency = (32 000 / 2.44) x 0.15 = 1969	C1 C1 C1 A0	Calculation in J: $E_{\text{X-ray photon}} = 32 \times 10^{3} \times 1.6 \times 10^{-19}$ $= 5.12 \times 10^{-15}$ (J) $E_{\text{X-ray photon}} = 32 \times 10^{3} \times 1.6 \times 10^{-19}$ $= 5.12 \times 10^{-15}$ (J) Number of photons = ($E_{\text{x-ray photon}}/E_{\text{light photon}}$) × efficiency = ($5.12 \times 10^{-15}$ / 3.90×10^{-19}) x 0.15 = 1969 Answer to at least 3sf **Allow** use of 2.4eV for energy of light photon to give 2000 in either method **<u>Examiner's Comments</u>** Most candidates were able to correctly show that the number of light photons was close to 1970. There were a number of methods and units that could be used and the inclusion of the 15% factor could be done at several points. Examiners were aware of these various routes and gave credit to working at each point where appropriate. The conversion of the keV to joules and the conversion of nm seemed to cause no difficulties.
	b	i	(The work function is) the minimum energy required to release an electron (from the surface of a metal)	B1	**Allow** minimum work done for minimum energy Do **not allow** idea of energy needed to release multiple electrons Do **not allow** release of electron from atom Do **not allow** idea of ionisation energy **<u>Examiner's Comments</u>** This explanation requires some specific detail; that it is a *minimum* energy and that it is not being applied to an atom. Nearly two thirds of candidates gave an explanation clear

					enough for credit and most of those who missed out on the mark simply weren't detailed enough rather than being wholly wrong. Responses such as 'the minimum energy for the photoelectric effect to occur' are not quite detailed enough.
		ii	$\phi = 2.3 \times 1.6 \times 10^{-19}$ (= 3.68×10^{-19} J) KE_{max} = (3.90 − 3.68) × 10^{-19} = 2.2×10^{-20} (J)	C1 A1	Or ϕ = 2.44 - 2.3 (= 0.14 eV) $KE_{max} = 0.14 \times 1.6 \times 10^{-19} = 2.2 \times 10^{-20}$ (J) Answer to at least 2sf **Allow** use of 2.4 eV to give 1.6×10^{-20} (J) ecf light photon energy from (a) **<u>Examiner's Comments</u>** Most candidates were able to obtain at least 1 mark by correctly converting the work function into joules. As always, correct working is very helpful in obtaining the intermediate marks. Several arranged the equation incorrectly, by adding on the work function, but well over half of the candidates correctly evaluated the maximum kinetic energy.
		iii	$I\left(=\frac{Q}{t}\right) = \frac{12 \times 1969 \times 1.6 \times 10^{-19}}{60}$ = 6.3×10^{-17} (A)	C1 A1	**Allow** full credit for use of 2000 Answer to at least 2sf (6.30) **Allow** use of N= 2000 to give $I = 6.4 \times 10^{-17}$ (A) **Allow** ecf on N from (a) **<u>Examiner's Comments</u>** A little under half of the candidates were able to correctly calculate the current. Incorrect methods included missing out the factor of 12, or by dividing by 3600 instead of 60.
		iv	One from: One to one interaction between (light) photon and electron That there are no secondary electrons That the current is continuous / X-rays arrive at a constant rate within the minute (or 1 every 5s)	B1	**<u>Examiner's Comments</u>** The main expectation for this question was to appreciate the one-to-one relation between the photon and the electron, although other valid answers were given. Ideas about efficiency are a little too limited for credit, along with statements like 'there are exactly 2000 photons'. Information in the question

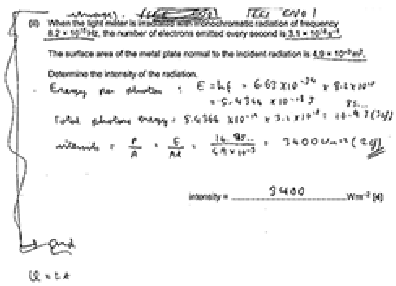
			All the electrons leave the photocathode		has to be treated as correct in any case, so is not an assumption.
			Total	**9**	
5			C	1	**<u>Examiner's Comments</u>** Approximately half of the candidates were able to correctly identify the order. Many set out the calculations to the side before putting them in rank order and this generally proved successful. Most of the incorrect responses showed little or no working, leading to the assumption that there may have been some guesswork involved.
			Total	**1**	
6			**Level 3 (5-6 marks)** Clear description of experiment and observations and detailed comparison of de Broglie wavelengths *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3-4 marks)** Some description of experiment **and** observations **and** some comparison of de Broglie wavelengths **or** Limited description of experiment and observations **and** detailed comparison of de Broglie wavelengths **or** Clear description of experiment and observations **and** limited comparison of de Broglie wavelengths *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1-2 marks)** Limited description of experiment and observations **or** Attempt at calculating the de Broglie wavelength of the car	B1 x 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description of experiment and observations** • Electrons accelerated by a (high) p.d. • In a vacuum • Electrons fired at a (graphite) target • Rings observed • Diagram showing rings (or apparatus set-up) • Due to diffraction between spacing of atoms • So wavelength ≈ spacing of atoms • Increase in accelerating p.d. decreases spacing of rings • Multiple layers of (graphite) atoms means diffraction occurs in all directions • Since diffraction occurs in all directions, rings are observed • Avoid touching the terminals / use insulated connections **Comparison of the Broglie wavelengths**

			There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant. **0 mark** *No response or no response worthy of credit.*		• λ electrons in the experiment ≈ 10^{-10} m • $\lambda = \frac{h}{p}$ • Estimate of mass of car: 500 kg to 3000 kg • Speed of car: 30.5 or 30.6 (279/9) m s^{-1} • λ car ≈ 7 × 10^{-39} m to 4 × 10^{-38} m • λ electrons >> λ car. **Examiner's Comments** Many candidates appeared not to understand an experiment to demonstrate the wave nature of electrons often drawing a diagram of a double slit and using a screen, in effect the Young slit experiment for light. High scoring candidates often either stated an estimate of the de Broglie wavelength of electrons or used their knowledge and calculated a value for an estimated value of the accelerating potential difference. Ther were some very good answers working out the de Broglie wavelength of a car. The best answers clearly showed the working.
			Total	**6**	
7	a	i	1.9 ×1.60 ×10^{-19} or 3.04 ×10^{-19} (3.0 ×10^{-19} J)	M1 A0	**Examiner's Comments** This question was well answered with the majority of candidates clearly writing 1.9 ×1.60 ×10^{-19} = 3.04 ×10^{-19} (J). This is exactly how a show type question should be answered.
		ii	$f = 990\ (\text{THz}) + \frac{3.0\times10^{-19}}{6.63\times10^{-34}}\ (= 1450\ (\text{THz}))$ $\lambda = \frac{3.0 \times 10^{8}}{1450 \times 10^{12}}$ λ = 2.1 ×10^{-7} (m) OR	C1 C1 A1 C1 C1 A1	**Allow** alternative methods **Note** 2.1 ×10^{n} scores two marks **Note** 6.6 ×10^{-7} scores zero (omits

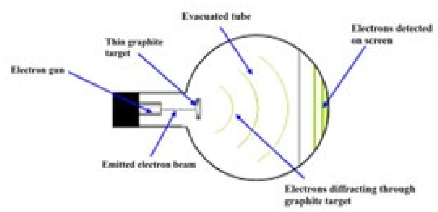
			Energy of photon = $6.56 \times 10^{-19} + 3.0 \times 10^{-19}$ (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{9.56 \times 10^{-19}}$ $\lambda = 2.1 \times 10^{-7}$ (m)		work function) **Note** 3.0×10^{-7} scores zero (omits energy of electrons) **Note** 2.1×10^{n} scores two marks **Examiner's Comments** Candidates found this question challenging. The common error was to omit the work function of the metal. Other candidates determined the energy but omitted the energy of the electrons. A significant minority of candidates attempted to answer this question by determining the momentum of the electrons. **Assessment for learning** Understand the differences between the photelectric effect and electron diffraction.
	b	i	no change / stays the same	B1	**Examiner's Comments** The majority of the candidates correctly stated that there would be no change. Some candidates then added good reasons to explain their answer.
		ii	doubles	B1	**Examiner's Comments** Most candidates correctly realised that the rate of emission would increase but many did not give a quantitative answer (double) to match the stem of the question. **Assessment for learning** Where quantitative data is used in questions, answers should also be quantitative wherever possible.

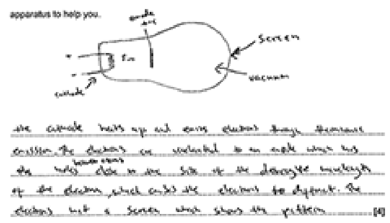
					Practice explaining the effect on one quantity due to another quantity is doubled/halved/quartered, etc.
	c	i	Any one from: • The <u>energy</u> from <u>photons</u> is absorbed by (photo)electrons • The <u>energy</u> of a <u>photon</u> is greater than the work function	B1	**<u>Examiner's Comments</u>** Many candidates did not mention photons in their answers. High performing candidates' answers were detailed and included the one-to-one interaction between one photon and one electron and the transfer of energy.
		ii	The <u>minimum</u> frequency of the incident radiation needed to emit a (photo)electron	B1	**ALLOW** The <u>minimum</u> frequency of the incident radiation needed to overcome the work function **<u>Examiner's Comments</u>** The majority of candidates gained a mark in this question. Candidates who did not gain the mark often referred to the minimum energy as opposed to the minimum frequency.
			Total	**8**	
8	a		photons mentioned electrons only emitted if the energy (of a photon) is equal to/greater than the work function energy (of photon) proportional to f / E = hf / E α f	B1 B1 B1	**<u>Examiner's Comments</u>** Just under two thirds of the candidates achieved 1 or more marks for correctly explaining the minimum energy required to emit electrons from incident photons related to the photoelectric effect. The most common response where candidates were given 1 mark was for relating the energy of radiation to the frequency by applying $hf = \Delta E$ but without referencing photons in their explanation and hence were not given any further marks. About 40% of candidates did reference photons in their response with 20% of candidates directly relating it to the work function as the minimum amount of energy required to release an electron to gain all 3 mark points.

	b	i	intensity of radiation is proportional to the rate of incident photons (above threshold frequency) AW (increased) one-to-one interaction between photons and electrons AW current is the rate of flow of charge/current = charge flow/time (so proportional to rate of electron release)	B1 B1 B1	**Examiner's Comments** Candidates did not perform well on this question as 60% of candidates achieved no marks. A common response was to describe that greater intensity leads to more photoelectrons which was not given, and few made the important connection between intensity and 'rate of photons hitting the plate'. Also, many candidates did not apply the 1:1 correlation between photons and electrons in the photoelectric effect as they simple stated that more electrons were released without applying knowledge of the individual interaction between incident photons to the release of electrons. Many took the reverse view that greater current led to greater intensity or simply referred to the ammeter reading rather than referencing current. Exemplar 2  This exemplar demonstrates a typical response from candidates where a simple statement is made in relation to the intensity of electrons emitted and corresponding current reading on the ammeter. As in many similar responses the intensity of radiation is not linked to the 'rate of incident photons' resulting in a similar 'rate of electron emission' due to the 1:1 interaction between photons and electrons. Candidates were then required to link the rate of electron emission to the equation $\Delta Q = I\Delta t$ to conclude that current is equal to the rate of flow of charge and hence the ammeter reading is proportional to the intensity of the radiation.
		ii	$6.634 \times 10^{-34} \times 8.2 \times 10^{15} / 5.44 \times 10^{-18}$ J	C1 C1	**ALLOW** 3439(.48)W m^{-2}

			$5.44 \times 10^{-18} \times 3.1 \times 10^{18} / 16.9$ (W) $\text{intensity} = \frac{16.9}{4.9 \times 10^{-3}}$ 3.4×10^{3} W m^{-2}	C1 A1	**<u>Examiner's Comments</u>** Candidates did not perform well on this question as just over half of candidates scored 0 marks. Candidates had to select the equations $hf = \Delta E$ and $I = P/A$ from the Data, Formulae and Relationship booklet and then apply that the power was equal to the energy as the rate of emission of electrons was in a time of 1 second. Many candidates would select the correct equation $I = P/A$ but would then try and calculate power by using the equation $P = VI$ and $\Delta Q = I\Delta t$ by using the charge of an electron to calculate the current and using the battery e.m.f. of 3 V given in the circuit diagram. This demonstrated for a majority of candidates a lack of a confident understanding of the photoelectric effect that the energy of incident photons results in the release of electrons. Exemplar 3  This response demonstrates the correct and clear selection and application of formulae to calculate the intensity of the incident radiation.
			Total	**10**	
9			D	1	**<u>Examiner's Comments</u>** About half of candidates performed well on this question by determining the correct answer of D by understanding that green light has a shorter wavelength and increased

					energy (due to having a greater frequency) compared to red light. The most common distractors were B and C.
			Total	**1**	
10			A	1	**Examiner's Comments** This question was answered well with the most candidates applying the equation $E = hf$ to give the correct answer A.
			Total	**1**	
11			A	1	**Examiner's Comments** Just over half of candidates answered this correctly and determined that the correct conditions for a diffraction pattern to be produced was when the spacing between atoms was roughly equal to the de Broglie wavelength of an electron. The most common distractor was D.
			Total	**1**	
12	a	i	Work done = $1.60 \times 10^{-19} \times 5 \times 10^{3}$ = **8.0×10^{-16}** (J)	A1	**ALLOW** correct answer to 1 significant figure **Examiner's Comments** The vast majority of candidates were able to carry out this simple calculation; most errors came from an incorrect conversion of kV rather than lack of knowledge of the calculation.
		ii	$W = ½ mv^2 = 8 \times 10^{-16} = ½ \times 9.11 \times 10^{-31} \times v^2$ = 4.2 x 107 ms^{-1} $\lambda = h/mv = 6.63\times10^{-34} / 9.11 \times 10^{-31} \times 4.2 \times 10^{7}$ = **1.7×10^{-11}** (m) OR	C1 A1 (C1) (A1)	Substitution leading to velocity Ecf from (c)(i) **ALLOW** correct answer to 1 significant figure Ecf from (c)(i) **ALLOW** correct answer to 1 significant figure

			Momentum of electrons = $\sqrt{2 \times m_e \times W}$ $= \sqrt{2 \times 9.11 \times 10^{-31} \times 8 \times 10^{-16}}$ = (3.82×10^{-23} kgms^{-1}) $6.63 \times 10^{-34} / 3.82 \times 10^{-23}$ = **1.74×10^{-11}** (m)		<u>**Examiner's Comments**</u> Around one half of candidates were able to correctly calculate the de Broglie wavelength. This is potentially difficult for the average candidate to carry out in a single calculation, so it is very helpful to show the working in a slightly extended calculation. Most candidates calculated the electron speed first from the kinetic energy equation and then correctly substituted it. Several candidates used the proton rest mass in place of the electron rest mass, but the majority of incorrect responses came from using the speed of light for the speed. This is a physics error which can score no marks.
		iii	(For diffraction to occur) the gap needs to be approximately the same size as the wavelength so spacing should be 1.74×10^{-11} m	B1	Reason <u>and</u> value required. **ALLOW** suggested value spacing as (c)(ii) same power of ten <u>**Examiner's Comments**</u> The justification for the spacing is in the context of the question and so must relate to their previously calculated value. Around half of the candidates correctly gave a value and supporting reason, which needed to relate their wavelength to the process of diffraction. Common incorrect answers included values of around 1fm (irrespective of their calculation) presumably from their knowledge of the nuclear radius.
	b		Any four from: In an evacuated tube (Electrons released by) thermionic emission / (low voltage supply causes) emission of electrons from cathode / filament / electron gun Electrons accelerated towards anode / electrons accelerated through (high) pd / electric field	4xB1	**ALLOW** marking points as labels on the diagram or as the answer lines. 

			Diffracted through a graphite (target) / graphite is thin Electrons detected on a (phosphor) screen / electrons produce visible light on impact with screen		**<u>Examiner's Comments</u>** A diagram is always helpful if suggested and candidates who drew a labelled diagram were often able to score marks that they would not have gained in the text. Candidates who had seen this experimental set-up were at an advantage and often gave good descriptions, although relatively few gained full marks. Several candidates confused anode and cathode and others assumed that the graphite was in some way responsible for the production of the electrons. Nearly one third of candidates scored no marks on this question; those who did often had little knowledge of the experiment although it is specifically mentioned in the specification. Incorrect responses included considering it as a ripple tank. Exemplar 1  This response shows a candidate using a diagram to gain marks that would not otherwise be covered in the text. The word 'vacuum' will score the first mark for the evacuated tube.
	c		(Provides evidence of) wave nature of electrons Light circles caused by constructive interference / waves arriving in phase Dark circles caused by destructive interference / waves arriving in antiphase	B1 B1 B1	**ALLOW** out of phase by 180 / π **NOT** just out of phase **<u>Examiner's Comments</u>** Most candidates appreciated that this was evidence of the wave nature of electrons, although a simple statement of 'wave-particle duality' does not really explain what the evidence provides. Although the circles could be described in terms of probability of electrons arriving, in the context of the question the concept of

					interference of the electron-waves was sufficient and was clearly the explanation that many candidates had been given and close to one half of candidates were able to achieve full marks.
			Total	**11**	
13		i	$\lambda_{max} \propto 1/T$ (T has decreased over time so in the past) the <u>peak</u> was at a shorter wavelength / further to the left on the graph	B1 B1	**Not** $\lambda_{max} = 1/T$ May be inferred from candidate's diagram **Ignore** overall shape of spectrum **<u>Examiner's Comments</u>** The mention of Wien's displacement law gave a clue that it would be useful in answering the question. A mark was given for stating the law. Note that the law is $\lambda_{MAX} \propto 1/T$ rather than $\lambda \propto 1/T$ or $\lambda_{MAX} = 1/T$. Candidates who did not draw on the diagram to illustrate their response sometimes missed the second B1 mark because they said that the wavelength (rather than the <u>peak</u> wavelength) would have been smaller. If an examiner says, 'You may draw on the diagram', it is generally a beneficial approach.
		ii	$E\left(=\frac{hc}{\lambda}\right)=\frac{6.63\times10^{-34}\times3\times10^{8}}{1.1\times10^{-3}}$ $E = 1.8 \times 10^{-22}$(J)	C1 A1	Full substitution needed if judging explicitly **<u>Examiner's Comments</u>** This was a straightforward question and most candidates correctly chose and applied the formula $E=\frac{hc}{\lambda}$ **Common problems in 4(b)(ii)** • not converting mm to m • trying to convert the answer to or from MeV
•		iii	**EITHER** $\frac{3\times10^{-6}}{1.8\times10^{-22}}$ **or** 1.66×10^{16} (photons m^{-2} s^{-1}) **OR** $3 \times 10^{-6} \times (150 \times 10^{-4})$ **or** 4.5×10^{-8}	C1	**Allow** 2×10^{14} (s^{-1}) or 3×10^{14} (s^{-1}) Expect to see $1.66 \times 10^{16} \times 150 \times 10^{-4}$ **or** $\frac{4.5\times10^{-8}}{1.8\times10^{-22}}$

			(W) number of photons per second $\left(= \frac{3 \times 10^{-6} \times 150 \times 10^{-4}}{1.8 \times 10^{-22}}\right)$ $= 2.5 \times 10^{14}$ (s^{-1})	A1	**Examiner's Comments** This is a complex, multi-stage calculation. A good approach was to use: number of photons per second × energy of each photon = amount of energy per second = power = intensity × area The total intensity of the microwave background radiation was given at the start of the question as 3×10^{-6} Wm^{-2}. Converting cm^2 into m^2 proved difficult for many.
		iv	$E = Pt = IAt$ and $V = Ah$ where A is CSA of cylindrical tank and h is height of tank $\Delta\theta = \frac{E}{mc} = \frac{IAt}{\rho A h c} = \frac{It}{\rho hc}$ and so $\frac{\Delta\theta}{t} = \frac{I}{\rho hc}$ $E = mc\theta$ **and** $m = \pi\rho V$ max temp rise s^{-1} $\left(= \frac{\Delta\theta}{t}\right) = \frac{3 \times 10^{-6}}{1000 \times 5 \times 4200}$ max temp rise $s^{-1} = 1 \times 10^{-13}$ (°C s^{-1})	C1 C1 A1	**Allow** nonstandard letters as long as meaning is clear **Allow** 1000 (kg m^{-3}) for ρ **Allow** $\pi r^2 h$ or $5\pi r^2$ for V **Allow** answer to more than 1s.f. (1.43×10^{-13} (°C s^{-1})) **Examiner's Comments** This too was a complex, multi-stage calculation. Most candidates correctly found their way into the question by writing down the formula $E = mc\Delta\theta$ and realising that they needed to use the formula $\rho = m/V$ in order to calculate the mass. The volume V of the cylindrical tank could be found using V = depth × cross-sectional area. However, although the depth was specified in the question, the cross-sectional area was not. Successful candidates realised that, if the cross-sectional area was not given, then it must cancel out later in the calculation. Some used algebra and called the cross-sectional area A. Others simply made up a value for A ($A = 1$ m^2 is the easiest).

			Total	9	
14	a	i	$a = \frac{VQ}{dm}$ OR $a = \frac{EQ}{m}$ OR $KE = ½ mv^2$ and $v^2 = u^2 + 2as$ OR $KE = F \times d$ and $F = m \times a$ $a = \frac{0.30 \times 1.6 \times 10^{-19}}{6.0 \times 10^{-3} \times 9.11 \times 10^{-31}}$ / $a = \frac{50 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$ / (Use of $KE = ½ mv^2$) = 4.8×10^{-20} = $½ \times 9.11 \times 10^{-31} \times v^2$ and (use of $v^2 = u^2 + 2as$ =) $v^2 = (1.05 \times 10^{11}) = 2 \times a \times 6 \times 10^{-3}$ (± 0^2) (Use of $KE = F \times d$) = $4.8 \times 10^{-20} = F \times 6 \times 10^{-3}$ and (use of $F = m \times a$) $F = (8.0 \times 10^{-18}) = 9.11 \times 10^{-31} \times a$ $a = 8.78 …. \times 10^{12}$ (ms^{-2})	C1 M1 A1	**Allow** u and v interchangeably throughout **Allow** calculation of E = (0.30 / 6 × 10^{-3}) = 50 (V m^{-1}) or $v = 3.2 \times 10^5$ (ms^{-1}) or $v^2 = 1.05 \times 10^{11}$ (ms^{-1})^2 or $F = 8.0 \times 10^{-18}$ (N) for C1 mark Substitution mark – in any arrangement. Expect full substitutions including numerical value of m_e if appropriate Method 1: direct calculation of a Method 2: using $KE = ½ mv^2$ and $v^2 = u^2 + 2as$ Method 3: using $KE = F \times d$ and $F = m \times a$ **Note** must be more than 2 SF (not paper SF penalty) **Ignore** negative sign **<u>Examiner's Comments</u>** There were many different routes to showing the acceleration, and marks were given for each method or part method. No one method was seen significantly more than others, and some candidates used a variety of pathways to come to their answer. The main principle in the question (and the subsequent one) where the candidate is being asked to "show that" a given value is correct is that the examiner must be convinced that the candidate has clearly demonstrated that they have carried out the calculation and evaluated it on their calculator. The instructions which examiners used was: first marking point for providing one (or two) equations that would lead to the solution, or calculation of an intermediate value; second marking point for a full substitution into one or

more equations; third marking point for using this full substitution to produce an answer to more sf than given in the question. As the second marking point was deemed to be an M mark, the full substitution needed to be seen to gain the A mark.

A small number of (often higher end) candidates did not show the full substitution, often missing out the value of m_e in their calculation, and another common error was to not show the extra significant figure.

Over half of the candidates were able to achieve full marks on this question and it generally discriminated well.

Assessment for learning

When a question asks a candidate to "show that" a given value is correct, the following two points should be considered:

- Each stage of the calculation should be clearly shown. Preferably setting out any equation first, and then showing a full substitution of all values into that equation
- If the value calculated by the candidate would correctly round to the given value, then the candidate should show their calculated value to at least one more significant figure than the given value.

Both of these are evidence that the complete calculation has taken place and that the candidate has not somehow artificially generated the required value. This advice should be viewed as "best practice" rather than a rigid set of rules.

Reverse arguments are often possible

					where a candidate can work backwards from their given value, however this is not the advised approach.
		ii	(Use of $KE = ½ mv^2$) = $4.8 \times 10^{-20} = ½ \times m \times v^2$ OR ($u^2 = v^2 - 2as$) = $0^2 - [2 \times (-)\ 8.8 \times 10^{12} \times s]$ Full substitution leading to $v = 3.2… \times 10^5$ (ms^{-1})	C1 A1	**Allow** u and v interchangeably Numerical value of m_e must be used if using *KE* method **Note** must be more than 1 SF (not paper SF penalty) **Note** 3.25 is acceptable for A1, but not 3.3 **<u>Examiner's Comments</u>** The vast majority of candidates were able to clearly show that the speed of the photoelectron could be calculated as 3.2×10^5 ms^{-1}, most often through substitution into the kinetic energy formula. As in Question 19 (b) (i), it is important to show all variables and constants used in the equation for full marks and to give the answer to at least one more d.p. than given in the question, to show the calculation has taken place. An alternative solution using an equation of motion and the acceleration given (or calculated) in Question 19 (b) (i) would yield the same result.
		iii	$t = \frac{3.2 \times 10^5}{8.8 \times 10^{12}}$ $t = 3.6 \times 10^{-8}$ (s)	C1 A1	**Allow** correct full substitution into any suvat equation **Allow** 3×10^5 for v **Ignore** signs of substituted values **Expect** values between 3.4×10^{-8} and 3.8×10^{-8} (s) **No ecf** from (b)(i) or (b)(ii) **<u>Examiner's Comments</u>** Only around half of the candidates were able to obtain answers within the required range. Candidates used a variety of rounded or none-rounded values from prior calculations, so a generous range of responses was given to allow for this. A common error among less successful responses was to simply use speed = distance/time

					usually leading to 2.0×10^{-8} s. Those using $s = ut + ½ at^2$ often encountered problems in solving the equation as it could lead to imaginary roots and tended to produce solutions way outside of the accepted values. However, marks could be given for setting up the calculation correctly.
		iv	Any line with negative slope starting from 0, 4.8×10^{-20} A straight line finishing at 6.0,0	M1 A1	½ square tolerance. **ALLOW** a curve with negative gradient. **ALLOW** a region of zero gradient, but not whole line ½ square tolerance on axis intercepted **<u>Examiner's Comments</u>** Nearly all candidates appreciated that this line would start at 4.8×10^{-20} J and decrease to zero at 6.0 mm. However, the vast majority drew a curved line of decreasing gradient. This may well have come from a confusion from $KE \propto v^2$ and attempting to draw a parabola.
	b		Energy of photon increases (max) kinetic energy / speed (of electrons) increases / (some) electrons (now) reach **C and** there is a current or reading (on ammeter)	B1 B1	**Do not allow** increased *kinetic* energy of photons **Do not allow** explanation in terms of increased number of **emitted** electrons (per second) **Allow** photoelectrons for electrons **<u>Examiner's Comments</u>** There were several misconceptions in candidates' responses to this question. Many candidates did not appreciate that the increased frequency would result in electrons of greater KE and thought that it was the increased energy of the photons crossing the 6.0mm gap that caused an ammeter reading. A significant number of candidates also described increasing frequency causing an increase in *kinetic* energy of photons, and some also linked the increasing frequency to a greater number of photons or photoelectrons.

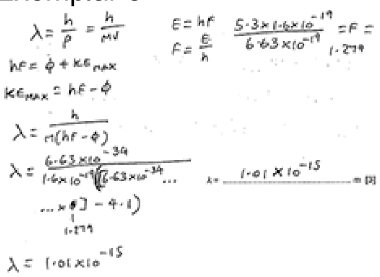
			Total	**11**	
15	a		*eV* or J → [kg m^2 s^{-2}] in base units by any method base units = kg m^2 s^{-1}	C1 A1	**Allow** kg $(ms^{-1})^2$ **Allow** base units in any order **<u>Examiner's Comments</u>** This question was done correctly by around half of the candidates. The most common method was to use an equation for energy or work to give the base units of the joule. From this, multiplying it by s would lead to the correct response. Most candidates used $KE = ½ mv^2$ to determine the base units of the joule directly, although others used work done = force × distance and force = mass × acceleration. Encouragingly, there were relatively few arithmetic errors even with the negative indices. Some candidates got into difficulties attempting to use the given equation and struggled with the volt, attempting to use $V = IR$ in a variety of ways. A very common error was to give the units simply as Js, often using $h = E\lambda/c$ to show [J × m / ms^{-1}] gives J s. There was a clear misconception (see below) about what constitutes a base unit. **Misconception** Candidates are reminded that base units are kg, m, s, A, K and mol. Other units are derived units.
	b		***Level 3 (5–6 marks)** Clear description of method **and** analysis of data *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description of method **and** analysis of data	B1 × 6	**Indicative scientific points may include**: **Description** • Circuit with LED connected to a variable supply (and series /current limiting resistor) / or use of variable resistor • p.d. across LED increased until LED emits light • Voltmeter (across LED) used to measure *V*

			or Clear description **or** Clear analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **or** Limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		• Use a range of LEDs • λ determined using diffraction grating / spectrometer / double-slit / use $n\lambda = d \sin\theta$ / $\lambda = ax/D$ **OR** λ determined from manufacturer's data / known wavelength • Darkroom used / tube placed over LED used to establish switching of LED / switch-on identified from finite ammeter reading **Analysis of data** • Plot of V against λ^{-1} / eV against λ^{-1} / eV against c/λ • Line of best-fit drawn through the points • Straight line (through origin) • Correct gradient for described graph hc/e or hc or h • Correct arrangement for determination of h h = (gradient × e) / c or h = gradient / c (allow numerical values for e *and/or* c) **<u>Examiner's Comments</u>** This level of response (LoR) question was designed to assess practical skills of planning, implementation, analysis and evaluation from module 4 of the specification, specifically 4.5.1(e). A holistic approach to marking is used, with marks given according to answers matching the descriptors for the various levels. No one answer is perfect for this question, examiners were expecting a varied approach which would lead to a correct determination of h. The nature of the question is such that it can be conveniently separated into a description of the experiment and an analysis of it. The key points in the description that examiners were looking for were:–a suitable circuit diagram allowing the

					potential difference across the LED to be both varied and measured – a description of the method used, specifically measuring the potential difference across the LED at the point at which it just lights – a statement or description of how the wavelength of the emitted light is determined or measured – use of a range of different wavelengths (or colours) of LEDs. The key points in the analysis that examiners were looking for were:–a suitable graph with appropriate variables on the correct axes – a description of how the graph will appear and what the gradient corresponds to – how the value of *h* can be determined from the gradient. It was clear that many candidates had carried out this experiment and were able to give good descriptions and analysis. The very best was detailed and well-structured and made every attempt to fully answer each section of the question. It was anticipated that the determination of the wavelength would come from an experimental method, but it was evident that many candidates who had carried this experiment out had used the manufacturer's data which is a perfectly acceptable response. It was important that candidates described how the potential difference across the LED was to be measured as this was specifically asked in the question and several candidates drew circuit diagrams which would not have worked in the required way, often with the variable resistor across the LED. Many candidates gave extra experimental details, such as using a darkroom, to help build up a detailed response. For the most part, the analysis was done better than the description and candidates were generally able to describe the correct graph and how to determine *h*. Several candidates plotted an incorrect graph, such as V against λ, which meant that they

					would not be able to determine *h*. Some of the responses were brief and used symbols with little explanation about how the analysis was to be carried out.
			Total	**8**	
16			($hf = \phi + KE_{max}$)= 6.63 ×10^{-34} × 6.3 × 10^{14} = ϕ + 4.8 × 10^{-20} ϕ = 3.6969 × 10^{-19} (J) ϕ = 2.3 (eV)	C1 C1 A1	**OR** (in eV) hf = 6.63 ×10^{-34} 6.3 × 10^{14} / 1.6 × 10^{-19} ϕ = 2.6 − 0.30 (eV) ϕ = 2.3 (eV) **Examiner's Comments** This question was successfully completed by many candidates. It was clear that the use of Einstein's equation was well known, and the conversion to eV (generally done at the end) only caused a few candidates difficulties, mostly by multiplying their work function (in J) by *e*. Several candidates wrote down the answer with no working – while this will score full marks here, it is a risky tactic should an arithmetic error occur on their calculator.
			Total	**3**	
17			**D**	1	**Examiner's Comments** Many candidates were able to correctly calculate the wavelength of the two particles and show that the correct response was D. Some calculated the wavelength of all of the particles from A to D, but the most elegant solutions were done through a variety of methods to determine some ratio or constant factor.
			Total	**1**	
18			**A**	1	**Examiner's Comments** This question was answered correctly by approximately half of the candidates. Most showed written

					working, often as $hf = 2mc^2$ or the equivalent in numerical form. **B** was by far the most common incorrect response, and it is clear from candidates working that the factor of 2 had simply been missed out.
			Total	**1**	
19		i	Energy (of photon) is less than work function/φ (of **C**) 3.3 (eV)	B1	**Allow** energy of photon / 3.2 (eV) < 3.3 (eV)/work function (of **C**) (so no photoelectrons) **<u>Examiner's Comments</u>** The highest 50% of candidates performed well on this question as they correctly referred to the 'energy of photons' while the bottom half tended to make vague and incomplete statements and hence did not compare the energy of photons to the work function of C.
		ii	190 (nm)	B1	**Allow** 194 (nm) from calculation E=hf **<u>Examiner's Comments</u>** Very few candidates realised that no use of $E = hc/\lambda$ was required to calculate the maximum wavelength as the work function of D was double of A so the maximum wavelength was half of 380 nm. Therefore, most candidates attempted to calculate the wavelength from the work function with a common error of not converting eV to J.
		iii	($hf = \varphi + KE_{max}$) $5.3 = 4.1 + KE_{(max)}$ **or** (KE_{max} =) 1.2 (eV) $\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = 1.2 \times 1.6 \times 10^{-19}$ $\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 6.4924 \times 10^5}$ $\lambda = 1.1 \times 10^{-9}$ (m)	C1 C1 A1	**Allow** KE = 1.92×10^{-19} (J) **Allow** $v = 6.5 \times 10^5$ (m s^{-1}) or $p = 5.9 \times 10^{-25}$ (kg m s^{-1}) **<u>Examiner's Comments</u>** Most candidates were able to convert eV to J but did not correctly use this to calculate the velocity of the photoelectrons as they did not apply the formula $\lambda = h/p$ to calculate the momentum. Only a few candidates correctly applied both formulae $hf = \varphi + KEmax$ and $\lambda = h/p$ to calculate the

					de Broglie wavelength. Exemplar 3 demonstrates typical responses from middle range candidates. **Misconception** Candidates did not apply the formula *hf* = φ + KEmax to determine the correct value for the KE and hence the momentum and used the value 5.3 eV given in the stem of the question. Exemplar 3  This response demonstrates a lack of understanding of the photoelectric effect and use and application of the formula *hf* = φ + KEmax. Candidates have selected the correct formula to calculate the de Broglie wavelength and have converted eV to J but have not understood that *p* is required to be calculated using *v* from the correct KE.
			Total	**5**	
20			A	1	**Examiner's Comments** Candidates performed well on this question as most gave the correct answer A as they identified that electrons are removed from the zinc plate.
			Total	**1**	
21	a		Any **three** from: • electrons have wave properties • (diffraction of electrons occurs when) the (de Broglie) wavelength is comparable / similar to the gap size • reason for the rings as opposed to linear pattern, e.g. graphite atoms are irregularly	B1 × 3	**Do not allow** electrons become / are waves **Examiner's Comments** This question gave opportunities for candidates to demonstrate their knowledge and understanding of a standard experiment. To improve answers to this question candidates

			arranged or graphite is polycrystalline • electron's (kinetic) energy transferred to light when the electrons collide with the screen • bright rings indicate maxima and/or dark rings minima.		needed to use the terms accurately. Many candidates stated that electrons can behave as a wave, however some candidates tended to state this is the wave particle duality rather than applying it to the question. Also, a popular answer was that the diffraction of electrons occurs because the de Broglie wavelength is comparable to the spacing in graphite. Some candidates also describe why circular rings were produced in terms of the irregular arrangement of graphite and there were also bright and dark rings. Few candidates stated that the kinetic energy transferred to light when the electrons collided with the screen.
	b		$p = \sqrt{2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 1800}$ OR 5.24×10^{-46} OR $\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 1800}}$ or 2.9×10^{-11} (m) 2.3×10^{-23} (kg ms^{-1})	C1 A1	**Examiner's Comments** This question was generally well answered. Many candidates realised that the denominator was momentum. Other candidates calculated the wavelength and then calculated the momentum. Some candidates omitted the 1800 V. A significant number of candidates omitted the question, presumably based on the perceived difficulty of the question. To assist candidates in the examination it may help if they write the numerical values beside each quantity. **Assessment for learning** When dealing with questions with powers of ten, write the equation down, then substitute the numbers including the powers of ten. It is worth calculating intermediate values and writing these down before calculating the final answer.

			Total	**5**	