6	**C is the correct answer** A is not correct because photoelectrons would have no kinetic energy at threshold frequency. B is not correct because this describes light emitted in an emission spectrum rather than light absorbed in the photoelectric effect. D is not correct because the frequency is not a maximum, and the electron should leave the surface rather than becoming excited.	1

10	**A is the correct answer** (Evidence for the wave nature of electrons came from experiments involving diffraction) B is not the correct answer C is not the correct answer D is not the correct answer	(1)

10	**B is the correct answer** A is not correct because gradient = $\frac{1}{hc}$ C is not correct because gradient = $\frac{1}{hc}$ D is not correct because gradient = $\frac{1}{hc}$	1

4	**C is the correct answer as the photoelectric effect can only be explained using the photon model of light.** A is not the correct answer as diffraction is demonstrated using waves B is not the correct answer as the Huygen's construction is demonstrated using waves D is not the correct answer as plane polarisation is demonstrated using waves	(1)

4	**A is the correct answer (de Broglie wavelength = 2.43 x 10^{-9} m)** B is not the correct answer as the de Broglie wavelength = 1.82 x 10^{-9} m C is not the correct answer as the de Broglie wavelength = 1.13 x 10^{-12} m D is not the correct answer as the de Broglie wavelength = 9.93 x 10^{-13} m	(1)

4	**B is the correct answer as increasing light intensity increases the number of electrons released per second (N), but does not affect the maximum kinetic energy of each released electron (E_k)** A is not the correct answer as the graphs show no effect on N and an effect on E_k C is not the correct answer as the graphs show an effect on E_k D is not the correct answer as the graphs show no effect on N	(1)

4	**C is the correct answer** A is not correct because this describes an energy of 1 J B is not correct because this describes a current of 1 A D is not correct because this describes a charge of 1 C

10	**The only correct answer is B** ($h = \frac{1}{c \times \text{gradient}}$) A is not correct because gradient = $\frac{1}{hc}$ C is not correct because gradient = $\frac{1}{hc}$ D is not correct because gradient = $\frac{1}{hc}$	1

9	**B is the correct answer as the momentum of a photon is h/λ** A is not the correct answer as momentum is mv C is not the correct answer as it is not the speed of light, but the speed of the electron. D is not the correct answer as h is a constant.	(1)

7	**B is the correct answer** A is not correct because the de Broglie wavelength would be 4λ. C is not correct because the de Broglie wavelength would be 0.5λ. D is not correct because the de Broglie wavelength would be 0.125λ.	1

7	**The only correct answer is A** B is not correct because an incorrect equation has been used C is not correct because the useful power output has been taken incorrectly to be 9.8 W	1
	D is not correct because an incorrect value for useful power output of 9.8 W has been used with the reciprocal of the correct equation	

9	**A 6.63×10^{-34} the gradient of an $E_{k\ max}$ vs f graph is the Planck constant (as $E_{k\ max} = hf - \varphi$)**	1
	Incorrect answers: B this is the mass of an electron C this is the charge of an electron D this is the speed of light in a vacuum	

9	**The only correct answer is C (The maximum kinetic of the photoelectrons energy depends on the frequency of the incident light.)** A is not correct as intensity only affects the number of photoelectrons released B is not correct because the frequency affects the kinetic energy of the photoelectrons D is not correct as the number of photoelectrons emitted per second depends on intensity	1

6	**B is the correct answer** ($hf = \Phi + KE_{max}$ so increasing f increases KE_{max}) A is not the correct answer as electrons are released instantaneously C is not the correct answer as increasing intensity only increases the number of electrons released and each electron still has the same kinetic energy D is not the correct answer as it is higher frequency, not wavelength, that eventually passes a threshold value to release electrons	(1)

4	**C is the correct answer** A is not correct because attraction between opposite charges is not evidence of wave behaviour B is not correct because the electrons are behaving as particles D is not correct because the electrons are behaving as particles	1

19(a)	A photon (incident on a surface) is absorbed by an atom / electron **Or** A photon (incident on a surface) collides with an atom / electron An electron gains energy and is emitted (from the surface)	(1) (1)	2

19(b)	(To cause the photoelectric effect) the energy (of a photon) must be greater than the work function (of the photocathode) **Or** (to cause the photoelectric effect) the frequency (of a photon) must be greater than the threshold frequency (of the photocathode) Photon energy is proportional to frequency, so photons below a certain frequency / energy cannot cause the photoelectric effect	(1) (1)	2

19(c)	Use of $1 \text{ eV} = 1.6 \times 10^{-19}$ J Use of $E = hf$ Use of $v = f\lambda$ Comparison of 840 nm with 700 nm and conclusion all wavelengths of visible light can be detected **Or** Comparison of 2.85×10^{-19} J with 2.37×10^{-19} J and conclusion all wavelengths of visible light can be detected **Or** Comparison of 1.78 eV with 1.48 eV and conclusion all wavelengths of visible light can be detected **Or** Comparison of 3.57×10^{14} Hz with 4.29×10^{14} Hz Example calculation $E = 1.48 \text{ eV} \times 1.6 \times 10^{-19} \text{ J eV}^{-1} = 2.37 \times 10^{-19}$ J $f_{threshold} = \frac{2.37 \times 10^{-19}\text{ J}}{6.63 \times 10^{-34}\text{ Js}} = 3.57 \times 10^{14}$ Hz $\lambda_{threshold} = \frac{3 \times 10^{8}\text{ m s}^{-1}}{3.57 \times 10^{14}\text{ Hz}} = 840 \times 10^{-9}$ m 700 nm < 840 nm so all wavelengths of visible light can be detected	(1) (1) (1) (1)	 4

19(d)	Use of $E_k = \frac{1}{2} mv^2$ Use of $V = \frac{W}{Q}$ Final kinetic energy = 1.81×10^{-17} (J) Example calculation Initial $E_k = 0.5 \times 9.11 \times 10^{-31} \text{ kg} \times (1.35 \times 10^{6} \text{ m s}^{-1})^2 = 8.30 \times 10^{-19}$ J $W = 108 \text{ V} \times 1.6 \times 10^{-19} \text{ C} = 1.73 \times 10^{-17}$ J Final kinetic energy ($= 1.73 \times 10^{-17} \text{ J} + 8.30 \times 10^{-19} \text{ J}$) $= 1.81 \times 10^{-17}$ J	(1) (1) (1)	 3

19(e)	**EITHER** Use of $V = IR$ to calculate current in circuit Calculates total p.d across resistors A to D Use of sum of e.m.f. = sum of p.d Internal resistance = 1.20 MΩ **OR** Calculates total p.d. across resistors A to D Uses ratio of resistance = ratio of p.d. Correct values substituted into ratio equation Internal resistance = 1.20 MΩ <u>Example calculation</u> $I = \frac{108\ \text{V}}{85 \times 10^3\ \Omega} = 1.27 \times 10^{-3}\ \text{A}$ $V = 1960 - 4 \times 108 = 1530\ \text{V}$ $r = \frac{1530\ \text{V}}{1.27 \times 10^{-3}\text{A}} = 1.20 \times 10^6\ \Omega$	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**4**

19(a)	Each photon (absorbed transfers all of its energy) to one electron The energy shared between the kinetic energy of the electron and the energy to break free Electrons need different amounts of energy to escape the surface (so kinetic energy of photoelectrons varies.)	**(1)** **(1)** **(1)**	**3**

19(b)	In the wave model, more intense light has greater amplitude waves **Or** In the wave model, more intense light means each wave transfers more energy (So) in the wave model light of any intensity would release (photo)<u>electrons</u> (In the particle model) intensity affects the number of <u>photons</u> (per second) **Or** (In the particle model) intensity does not affect the energy of each <u>photon</u> (But) ultraviolet photons / light have more energy than a visible light so ultraviolet would cause the release of (photo)<u>electrons</u> (So) this demonstrates the particle nature of light	**(1)** **(1)** **(1)** **(1)** **(1)**	**5**

19(c)	Use of $c = f\lambda$ with with c = 3 x 10^8 ms^{-1} Use of E = hf Use of $hf = \varphi + E_{\text{k max}}$ Converts from J to eV or Use of $V = \frac{W}{Q}$ $E_{\text{k max}} = 0.66$ (e)V < 1.5 (e)V so no current is detected **Or** $E_{k\ max} = 1.1 \times 10^{-19}$ J $< 2.4 \times 10^{-19}$ J so no current is detected **Or** photon energy required = 9.30 x 10^{-19} J > 7.96 x 10^{-19} J so no current is detected <u>Example calculation</u> $f = \frac{3.00 \times 10^8 \text{ m s}^{-1}}{250 \times 10^{-9} \text{ m}} = 1.2 \times 10^{15}$ Hz 6.63×10^{-34} J s $\times 1.2 \times 10^{15}$ Hz $= 6.9 \times 10^{-19}$ J $+ E_{\text{k max}}$ $E_{\text{k max}} = 7.96 \times 10^{-19}$ J $- 6.9 \times 10^{-19}$ J $= 1.06 \times 10^{-19}$ J $E_{\text{k max}} = \frac{1.06 \times 10^{-19} \text{ J}}{1.6 \times 10^{-19} \text{ J eV}^{-1}} = 0.663$ eV 0.663 eV < 1.5 eV so no current is detected	**(1)** **(1)** **(1)** **(1)** **(1)**	**5**
	Total for question 19		**13**

Question Number	Answer		Mark
16a	(Sodium) electrons/atoms gain/absorb energy And electrons move to higher energy levels (Sodium) electrons drop to lower energy levels, releasing photons (For MP2 & MP3, allow excited and de-excited) (For MP2 & MP3, do not allow "atoms" for "electrons") (For "levels" accept shells, orbitals, states)	(1) (1) (1)	**3**
16b	Use of $c = f\lambda$ **and** Use of $E=hf$ Converts J to eV Energy = 2.11eV Example of calculation $f = (3.00 \times 10^8 \text{ m s}^{-1}) / (589 \times 10^{-9} \text{ m}) = 5.09 \times 10^{14}$ Hz $E = (6.63 \times 10^{-34} \text{ Js}) \times (5.09 \times 10^{14} \text{ Hz}) = 3.38 \times 10^{-19}$ J E (in eV) = $(3.38 \times 10^{-19} \text{ J}) / (1.60 \times 10^{-19} \text{ J eV}^{-1}) = 2.11$eV	(1) (1) (1)	**3**
16c	Uses $\tan\theta = s / D$ Use of $n\lambda = d\sin\theta$ with $n = 1$ Grating has 301 lines / mm, so the label is correct. **OR** Uses $sin\theta = \frac{s}{\sqrt{(s^2+D^2}}$ Use of $n\lambda = d\sin\theta$ with $n = 1$ Grating has 301 lines / mm, so the label is correct. (Use of double slit or single slit equations does not gain any credit) (Allow reverse calculation to show that 300 lines per mm leads to a value of λ that is close to the given value or that 300 lines per mm leads to a value of d or θ that is close to a value calculated). Example of calculation $\tan\theta = 0.234 \text{ m} / 1.30 \text{ m} = 0.18$ $\theta = 10.2°$ $n\lambda = d\sin\theta$, so d = $589 \times 10^{-9} \text{ m} / \sin 10.2° = 3.33 \times 10^{-6}$ m lines per mm = $1 / 3.33 \times 10^{-3} \text{ m} = 301$.	(1) (1) (1) (1) (1) (1)	**3**
	Total for question 16		**9**

17(a)(i)	Use of $E = hf$ $f = 5.19 \times 10^{14}$ Hz Example of calculation $f = \dfrac{3.44 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ J s}} = 5.189 \times 10^{14}$ Hz	**(1)** **(1)**	**2**

Question Number	Answer		Mark
*17(a)(ii)	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content.		

IC points	IC mark	Max linkage mark	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

The following table shows how the marks should be awarded for structure and lines of reasoning.

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

IC1 The potential difference causes a current in the gas / tube
IC2 So energy is transferred to the gas atoms
IC3 Electron/atom gains (sufficient) energy to move up energy levels
IC4 An (excited) electron (is unstable and) falls back down emitting a photon
IC5 With a wavelength/frequency corresponding to the difference in the energy levels Or reference to $E = hf$ or $E \propto f$
IC6 Electrons/atoms exist in discrete/fixed/certain energy levels so only certain frequencies / wavelengths are emitted

6

17(b)(i)	Use of 1 eV = 1.6×10^{-19} J	(1)	
	Use of $hf = \phi + \frac{1}{2}mv_{max}^2$	(1)	
	$v_{max} = 5.34 \times 10^5$ m s^{-1}	(1)	**3**
	<u>Example of calculation</u> $4.75 \text{ eV} \times 1.6 \times 10^{-19} \text{ J eV}^{-1} = 7.6 \times 10^{-19}$ J $7.6 \times 10^{-19}\text{J} = 6.3 \times 10^{-19}\text{J} + \frac{1}{2} \times 9.11 \times 10^{-31}\text{kg} \times v_{max}^2$ $v_{max} = 534\,000$ m s^{-1}		

17(b)(i)	Use of 1 eV = 1.6×10^{-19} J Use of $hf = \phi + \frac{1}{2}mv_{max}^2$ $v_{max} = 5.34 \times 10^5$ m s^{-1} <u>Example of calculation</u> $4.75 \text{ eV} \times 1.6 \times 10^{-19} \text{ J eV}^{-1} = 7.6 \times 10^{-19} \text{ J}$ $7.6 \times 10^{-19}\text{J} = 6.3 \times 10^{-19}\text{J} + \frac{1}{2} \times 9.11 \times 10^{-31}\text{kg} \times v_{max}^2$ $v_{max} = 534\,000 \text{ m s}^{-1}$	**(1)** **(1)** **(1)**	**3**
17(b)(ii)	Use of $p = mv$ and $\lambda = \frac{h}{p}$ $\lambda = 1.4 \times 10^{-9}$ m <u>Example of calculation</u> $\lambda = \frac{6.63 \times 10^{-34} \text{ J s}}{9.11 \times 10^{-31}\text{kg} \times 5.3 \times 10^5 \text{ m s}^{-1}} = 1.37 \times 10^{-9}\text{m}$	**(1)** **(1)**	**2**
	Total for question 17		**13**

Question Number	Answer	Mark
19(a) (i)	Use of $E=hf$ (to find photon energy) (1) $E = 1.3 \times 10^{-18}$ (J) (1) The <u>photon</u> energy is greater than the work function (1) So electrons (have sufficient energy to be) released (from the surface of the zinc) and the electroscope loses <u>charge</u> (1) **OR** Use of $\emptyset = h f_0$ (to find threshold frequency) (1) $f_0 = 1.0 \times 10^{15}$ (Hz) (1) The frequency of the UV is greater than the threshold frequency (1) So electrons (have sufficient energy to be) released (from the surface of the zinc) and the electroscope loses <u>charge</u> (1) **OR** Use of KE = $hf - \emptyset$ (to find kinetic energy of electrons) (1) KE = 6.4×10^{-19} (J) (1) Kinetic energy value is positive (1) So electrons (have sufficient energy to be) released (from the surface of the zinc) and the electroscope loses <u>charge</u> (1) <u>Example of Calculation</u> $E = hf = 6.63 \times 10^{-34}$ J s $\times 2.0 \times 10^{15}$ Hz $E = 1.3 \times 10^{-18}$ J	**4**
19(a)(ii)	One photon interacts with one electron (1) (Same frequency so) photon/light/UV energy remains constant (1) (At a lower intensity) there are fewer photons per second **Or** (at a lower intensity) there are fewer (photo)electrons per second (1) So gold leaf's deflection would reduce more slowly **Or** so gold leaf takes more time to fall (1)	**4**

19(b)	**Max 3 from** Electrons are released instantaneously (even at low intensity) **Or** in the wave model electrons would be released after a delay There is a minimum frequency for releasing electrons **Or** in the wave model electrons are released at any frequency More intense light does not increase (kinetic) energy of electrons **Or** in the wave model more intense light increases (kinetic) energy of electrons There is a maximum kinetic energy of electrons for a specific frequency **Or** in the wave model there is no maximum kinetic energy of electrons for a specific frequency	 (1) (1) (1) (1)	 **3**
	Total for question 19		**11**