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

3	**A is the correct answer** B is not correct because this would give the momentum of the electron C is not correct because this gives $\frac{1}{\text{velocity}}$ D is not correct because this would give $\frac{1}{\text{momentum}}$ for the electron

5	**D is the correct answer as $v = \frac{h}{\lambda m}$** A is not the correct answer as v is not equal to $\frac{m}{h\lambda}$ B is not the correct answer as v is not equal to $\frac{\lambda m}{h}$ C is not the correct answer as v is not equal to $\frac{h\lambda}{m}$	(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)

9	**D is the correct answer** A is not the correct answer as this corresponds to the smallest energy change B is not the correct answer as this corresponds to the smallest energy change C is not the correct answer as this corresponds to the smallest energy change	(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

10	**B is the correct answer** A is not correct because E_1 should be added to the energy of the photon. C is not correct because the speed of light should be part of the numerator and wavelength should be the denominator and E_1 should be added to the energy of the photon. D is not correct because the speed of light should be part of the numerator and wavelength should be the denominator.	1

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

Question Number	Answer		Mark
14a	Minimum energy required to release/emit a (photo)electron (from the surface of the metal)	(1)	**(1)**
14b	Ultraviolet has a higher (photon) energy (than visible light) Ultraviolet (photons) have an energy greater than the work function **Or** Visible light (photons) have an energy less than the work function **OR** Ultraviolet has a higher frequency (than visible light) Ultraviolet has a frequency greater than the threshold frequency **Or** Visible light has a frequency less than the threshold frequency (Allow converse statements for MP1)	(1) (1) (1) (1)	**(2)**
14ci	(Increased intensity means) more <u>photons</u> per second (More photons leads to) more electrons emitted (per second) Reading on ammeter is increased **Or** Current is increased (For MP1 there needs to be an indication of rate e.g. "per unit time")	(1) (1) (1)	**(3)**
14cii	Use of $E = hf$ Use of $V = W/Q$ Use of $hf = \Phi + \frac{1}{2} mv^2_{max}$ Work function = 7.6×10^{-19} (J) **<u>Example of Calculation</u>** $hf = \Phi + \frac{1}{2} mv^2_{max} = hf = \Phi + QV$ $hf = (6.63 \times 10^{-34}\ \text{Js})(2.00 \times 10^{15}\ \text{Hz}) = 1.33 \times 10^{-18}$ J $QV/eV = (1.60 \times 10^{-19}\ \text{C})(3.59\ \text{V}) = 5.74 \times 10^{-19}$ J hf – eV = 7.56×10^{-19} J	(1) (1) (1) (1)	**(4)**
	Total for question 14		**10**

Question Number	Answer		Mark
14a	(In the wave model) <u>energy</u> is built up over time **Or** (in the wave model) the <u>energy</u> is spread across the wave So (photo)<u>electron</u>s would not be released immediately/instantaneously **Or** so (photo)<u>electron</u>s would be released after a time delay (MP1 – allow any wording indicating a time delay e.g. 'slowly') (MP2 – do not allow "photoelectric emission" unless it is directly linked to <u>electron</u> release)	(1) (1)	**2**
14bi	Use of $hf = \Phi + ½mv^2_{max}$ Converts from eV to J Use of $E_k = ½mv^2$ (with $m = 9.11 \times 10^{-31}$) Maximum speed of electrons = 7.3×10^5 ms^{-1} <u>Example of calculation</u> Φ (in J) = 4.3 eV × (1.6 × 10^{-19} J eV^{-1}) = 6.9 × 10^{-19} J $hf - \Phi = ½mv^2 = (9.3 \times 10^{-19}\ \text{J}) - (6.9 \times 10^{-19}\ \text{J}) = 2.4 \times 10^{-19}$ J 2.4×10^{-19} J = ½ (9.11 × 10^{-31} kg) v^2 $v = 7.3 \times 10^5$ ms^{-1}	(1) (1) (1) (1)	**4**
14bii	Lower work function (than zinc) would result in greater (maximum) speed (of electrons) Greater wavelength (of ultraviolet light) would result in smaller (maximum) speed (of electrons) **Or** to achieve greater (maximum) speed (of electrons), a smaller wavelength would be required The relative sizes of these changes are not known so no conclusion could be reached **Or** the first suggestion is correct, the second is incorrect (MP1/MP2 – ignore references to KE)	(1) (1) (1)	**3**
	Total for question 14		**9**

Question Number	Answer		Mark
11	Electrons can behave as waves Because the rings show diffraction / interference	**(1)** **(1)**	**2**
	Total for question 11		**2**

Question Number	Answer		Mark
*17(a)(i)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Photon energy greater than the work function (of the metal) **Or** Electrons gain energy greater than the work function (of the metal) (so that) electrons are emitted (from the surface of the metal) **For Positive p.d**: The electrons are accelerated/attracted towards Q (creating a current) **For negative p.d:** The idea that the (released) electrons need (kinetic) energy to reach Q **Or** The electrons decelerated/repelled by Q At V_s no electrons have sufficient energy to reach Q (so no current)	 **(1)** **(1)** **(1)** **(1)** **(1)**	**5**
17(a)(ii)	Intensity related to number of photons per second Double the electrons (per second)	**(1)** **(1)**	**2**
17(b)	Use of $hf = \varphi + \frac{1}{2} mv^2_{max}$ Conversion eV to J (See 6.82 x 10^{-19} (J) or 4.26 x 1.6 10^{-19}) $V_S = 0.71$ V <u>Example of calculation</u> Max ke = $(6.63 \times 10^{-34}$ Js $\times 1.2 \times 10^{15}$ Hz$) - (4.26 \times 1.6 \times 10^{-19}$ C$)$ $= 7.96 \times 10^{-19}$ J $- 6.82 \times 10^{-19}$ J $= 1.14 \times 10^{-19}$ J Max ke = 1.14×10^{-19} J $\div 1.6 \times 10^{-19}$ C $V_S = 0.71$ V	**(1)** **(1)** **(1)**	**3**
	Total for question 17		**10**