Question Number	Answer	Mark
1(a)	Photon – quantum/packet of something relevant e.g. light, radiation, any other named e-m radiation, energy **(1)** (quantum/packet) of <u>electromagnetic</u> energy/radiation/waves (dependent mark) **(1)**	**2**
(b)	Use of $(20.66 – 18.70) \times 1.6 \times 10^{-19}$ **(1)** Use of $E = hf$ (with energy in eV or J) **(1)** $f = 4.7 \times 10^{14}$ Hz **(1)** <u>Example of calculation</u> $f = (20.66 – 18.70) \times 1.6 \times 10^{-19} / 6.63 \times 10^{-34}$ $f = 4.73\times 10^{14}$ Hz	**3**
(c)	From kinetic energy of atoms **(1)**	**1**
(d)	Diffraction **(1)** Light spreads (sideways) as it passes through the slit **(1)** Narrower slit causes more diffraction/spreading **Or** diffraction increasing as gap width gets closer to wavelength **(1)**	**3**
	Total for question	**9**

Question Number	Answer	Mark
2(a)	Observations: Most alpha went straight through / undeflected (1) [Do not credit just "alphas go through"] Some / few deflected [not "reflected] (1) Very few / < 1 in 1000 came straight back / were deflected through very large angles (>90°) / were reflected (1)	**3**
(b)(i)	Any mention of tubes (1) Alternating p.d. / a.c. p.d. /alternating electric field (1) Length of tubes increases (1)	**3**
(b)(ii)	Use of $p = E/c$ with $c = 3 \times 10^8$ (1) (Use of de Broglie) $\lambda = h/p$ with $h = 6.6 \times 10^{-34}$ (1) wavelength = 6.2×10^{-17} m (1) Example of answer $p = 20 \times 1.6 \times 10^{-10}$ J / 3×10^8 m s^{-1} = 1.1×10^{-17} N s Correct sub of h and p i.e. $\lambda = 6.6 \times 10^{-34} / 1.1 \times 10^{-17}$ N s	**3**
(b)(iii)	Wavelengths need to be smaller than nuclei [allow same as / similar to – must be comparative] (1)	**1**
(b)(iv)	Proton is not uniform / has space (1) Contains quarks (1) [ignore any reference to charge]	**2**
(b)(v)	Kinetic energy is not conserved (1) [K.E. and momentum not conserved – do not credit]	**1**
	Total for question	**13**

Question Number	Answer		Mark
3(a)	photon absorbed by electron electron moves to higher energy level **Or** electron excited where photon energy = difference in energy levels only certain changes/differences possible between discrete energy levels	**(1)** **(1)** **(1)** **(1)** **(1)**	**5**
3(b)(i)	Use of $E = hf$ Use of conversion factor to eV Energy of photon = 1.91 (eV) Identify levels 3.41 (eV) and 1.51 (eV) **Or** levels 1 and 2 Example of calculation $E = 6.63 \times 10^{-34}$ J s $\times 4.6 \times 10^{14}$ Hz (= 3.05×10^{-19} J) $E = 6.63 \times 10^{-34}$ J s $\times 4.6 \times 10^{14}$ Hz $\div 1.6 \times 10^{-19}$ J s = 1.91 eV = 3.41 eV − 1.51 eV (1.90 eV) as the closest match	**(1)** **(1)** **(1)** **(1)**	**4**
3(b)(ii)	Just-free electrons have zero energy state **Or** energy value of level $n = \infty$ is 0 (Bound) electrons need to gain energy to attain this state **Or** electrons need to gain energy to move to a higher level (Accept Because they must gain energy to move up for second mark) (accept answers in terms of ionisation energy)	 **(1)** **(1)**	**2**
3(c)	Look for corresponding pattern of lines / frequency spacings at different place in spectrum **Or** reference to known normal positions moving away increases observed wavelength / decreases frequency (or the case for moving towards) so if shifted to red end then moving away (or blue = towards) **Or** the greater the velocity the greater the change in frequency	**(1)** **(1)** **(1)**	**3**
	Total for question		**14**

Question Number	Answer		Mark
4(a)	The wavelength (associated) with a particle/electron with a given momentum **Or** $\lambda = h/p$ all terms defined	**(1)** **(1)** **(1)** **(1)**	 **2**
4(b)(i)	Use of $E_k = eV$ Use of $E_k = p^2/2m$ **Or** use of $E_k = mv^2/2$ **and** $p = mv$ Momentum = 1.21×10^{-23} kg m s^{-1} <u>Example of calculation</u> $E_k = 1.6 \times 10^{-19}$ C$\times$ 500 V $p^2 = 2\ m\ E_k = 2 \times 9.11 \times 10^{-31}$ kg $\times$ ($1.6 \times 10^{-19} \times 500$) J $p = 1.21 \times 10^{-23}$ kg m s^{-1}	**(1)** **(1)** **(1)**	 **3**
4(b)(ii)	Use of $\lambda = h/p$ $\lambda = 5.49 \times 10^{-11}$ m (ecf value of p from (i)) (show that value gives 6.63×10^{-11} m) <u>Example of calculation</u> $p = 6.63 \times 10^{-34}$ J s / 1.21×10^{-23} kg m s^{-1} $\lambda = 5.49 \times 10^{-11}$ m	**(1)** **(1)**	 **2**
	Total for question		**7**