9(a)	emission of electrons (from a metal surface)	**M1**
	when electromagnetic radiation is incident (on surface)	**A1**

9(b)(i)	threshold frequency = 2F	**A1**

9(b)(ii)	Planck constant = Φ / F	**A1**

9(c)	two diagonal straight lines with positive gradient in the positive E_K region only, starting at non-zero values of f	**B1**
	line labelled X passing through (F, 0) **and** line labelled Y passing through (2F,0) and extending to 3F or +2Φ	**B1**
	two diagonal straight lines with equal gradients	**B1**
	X line extrapolates back to (0, –Φ) **and** Y line extrapolates back to (0, –2Φ)	**B1**

Question 9

(a) The majority of the candidates gained full credit. Some specified that the incident radiation was light, and others referred to electrons being excited but not emitted.

(b) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer. Some stated the value of the Planck constant rather than giving an expression.

(c) Many candidates gained full credit. Some candidates incorrectly showed the lines extending with negative kinetic energy, although dashed lines were treated as construction lines to demonstrate the intercept on the E_K axis of the extrapolated line and ignored. Some candidates did not label the lines X and Y. Some candidates drew only one line and gained no credit.

8(a)	*Any three points from*: • electrons moving between levels emit a single photon • energy of photon = difference between energy levels • energy of photon depends on frequency • discrete frequencies (in spectrum) so differences between electron energies must be discrete • discrete differences between electron energies means energy levels must be discrete	**B3**

8(b)(i)	energy $= -(13.6 \times 1.60 \times 10^{-19})$ $= -2.18 \times 10^{-18}$ J	**A1**

8(b)(ii)	$\Delta E = hf$	**C1**
	$= (6.63 \times 10^{-34} \times 2.47 \times 10^{15}) / (1.60 \times 10^{-19}) = 10.2$ eV	**A1**

8(b)(iii)	$n = 2$ energy level $= -3.4$ eV	**A1**
	$n = 3$ energy difference $= 12.1$ eV	**A1**
	$n = 4$ energy difference $= 12.8$ eV	**A1**
	$n = 3$ energy level $= -1.5$ eV **and** $n = 4$ energy level $= -0.8$ eV	**A1**

Question 8

(a) Many candidates attempted to explain why the photoelectric effect has a threshold frequency rather than answering the question that was asked.

(b) (i) Common reasons for credit not being awarded in this question were either giving an answer that was positive rather than negative, or giving an answer to fewer than the three significant figures warranted by the data in the question.

(ii) This question was well answered by many candidates. Some of the weaker candidates thought they had to work out a difference in the energies represented by two frequencies, rather than appreciating that the frequency of each line relates to a difference in energy levels.

(iii) Some candidates were able to determine one column correctly but not the other, leading to partial credit. Stronger candidates in general were able to achieve full credit.

8(a)	packet / quantum of <u>energy</u>	**M1**
	of electromagnetic radiation	**A1**

8(b)(i)	$E = c^2 \Delta m$	**C1**
	$\Delta m = (4.274 \times 10^6 \times 1.60 \times 10^{-19}) / (1.66 \times 10^{-27} \times (3.00 \times 10^8)^2)$ (= 0.00458 u)	**C1**
	m = 233.915174 + 4.000407 + 0.00458 = 237.92016 u	**A1**

8(b)(ii)	$E = hc / \lambda$ **or** $E = hf$ **and** $c = f\lambda$	**C1**
	$(4.274 - 4.200) \times 1.60 \times 10^{-13} = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / \lambda$	**C1**
	$\lambda = 1.7 \times 10^{-11}$ m	**A1**

8(b)(iii)	(true) energy of gamma photon is smaller so (true) wavelength is larger	**B1**

8(c)	(anti)neutrinos are emitted during beta decay	**B1**
	particles emitted during beta decay carry varying amounts of energy, so energy of gamma photon is also variable (between decays)	**B1**

Question 8

(a) There was a good understanding of the nature of the photon amongst most candidates.

(b) (i) To successfully answer this question, candidates needed to maintain the use of six decimal places in their calculations to match the data provided. Most candidates attempted to use the equation $E = mc^2$ but only stronger candidates converted the energy released into a mass in u to then be added to the other two masses.

(ii) The correct equation was used by most candidates. Stronger candidates were able to follow through the subtraction of energies that gave the value for the energy of the gamma photon.

(ii) Stronger candidates identified that they should be describing the energy of a gamma photon and its relationship to wavelength.

(c) Candidates who mentioned another product of the decay usually knew the correct product. Weaker candidates were unaware of the impact of the energy sharing between the products on the energy available to each gamma photon. Stronger candidates appreciated that each decay involved a single gamma photon.

9(a)(i)	electromagnetic wave can behave like a particle	**B1**
	moving particle can behave like a wave	**B1**

9(a)(ii)	$\lambda = h / p$	**M1**
	h is the Planck constant	**A1**

9(b)(i)	*Any two points from:* • pattern similar to diffraction of light • diffraction (pattern) is characteristic of wave behaviour • rings show constructive and destructive interference	**B2**

9(b)(ii)	(de Broglie) wavelength decreases	**B1**
	rings become closer together	**B1**

Question 9

(a) (i) Candidates were more likely to discuss examples exclusively, rather than describe the general picture of wave–particle duality. The particle-like behaviour of an electromagnetic wave was the half of the required answer that was most successfully described. It was rarely mentioned that a particle needed to be moving to show wave-like properties.

(ii) This question was generally well answered.

(b) (i) Candidates who focused on what wave nature entailed were more successful in this question. The opportunity to compare the pattern shown with that of other waves was rarely taken. Interference was mentioned by some candidates but often without identifying that the light and dark rings represented regions of constructive and destructive interference.

(ii) The reduction of the de Broglie wavelength was well understood by most candidates, and descriptions of how that occurred were often very accurate. Descriptions of the change to the pattern, on the other hand, were often too imprecise to be given credit, weaker examples being the use of the words ‘pattern’ or ‘lines’ rather than ‘rings’ or ‘circles’.

9(a)	emission of electrons (from a metal surface)	**B1**
	when electromagnetic radiation is incident (on surface / electrons)	**B1**

9(b)(i)	current falls to zero when applied voltage equals energy per unit charge of emitted electrons	**B1**
	energy of photon depends on frequency	**B1**
	maximum energy of electron depends on energy of photon	**B1**

9(b)(ii)	*Any three points from:* • threshold frequency = 1.5×10^{15} Hz • threshold wavelength = 2.0×10^{-7} m • work function = 6.2 eV (or 9.9×10^{-19} J) • Planck constant = 6.6×10^{-34} J s (**not** 6.63×10^{-34} J s) • number per unit time (of photons / electrons) = $1.7 \times 10^{16}\ s^{-1}$ (in stage 1) • power of incident radiation = 0.028 W (in stage 1)	**B3**

Question 9

(a) This question was generally well answered, with most candidates able to state that the photoelectric effect is the emission of electrons from a metal surface when electromagnetic radiation is incident upon it. Some weaker candidates confused the roles of the photons and the electrons in the process.

(b) (i) Many candidates misunderstood the point of this question and discussed in detail why a threshold frequency exists for photoelectric emission. Candidates who realised that this question was all about the maximum kinetic energy of the electrons after emission were more successful in gaining credit. Many candidates were too vague in their discussion of 'energy', often just using the term generically despite there being three different energies involved in the process (photon energy, work function energy and electron kinetic energy). To achieve credit, candidates needed to be clear which of these energies they were referring to when discussing 'energy'.

(ii) Many candidates found this question difficult, either giving qualitative rather than quantitative conclusions, or simply giving descriptions of the graphs rather than drawing conclusions from them. Quantities that candidates could calculate from the graph data to achieve credit included the threshold frequency of the metal, the threshold wavelength, the work function, a value for the Planck constant, the number per unit time of incident photons and the power of the incident radiation. In answering this type of question, candidates should be advised that they need to give all calculated values with a correct unit and to an appropriate number of significant figures.

8(a)	wavelength associated with a moving particle	**B1**

8(b)	$\lambda = h / p$	**C1**
	$= (6.63 \times 10^{-34}) / (9.11 \times 10^{-31} \times 4.9 \times 10^{7})$ $= 1.5 \times 10^{-11}$ m	**A1**

8(c)	similarity: *any one point from*: • same mass • same <u>magnitude</u> of charge • both leptons	**B1**
	difference: *any one point from*: • electron has negative charge, positron has positive charge • positron is anti-particle of electron • electron is a particle, positron is an anti-particle	**B1**

8(d)(i)	(pair) annihilation	**B1**

8(d)(ii)	their mass gets converted into energy	**B1**
	(their mass–energy) becomes the energy of the gamma photons	**B1**

8(d)(iii)	they travel in opposite directions to conserve momentum	**B1**

8(d)(iv)	kinetic energy $= \frac{1}{2} \times 9.11 \times 10^{-31} \times (4.9 \times 10^{7})^2 = 1.1 \times 10^{-15}$ J	**A1**

8(d)(v)	$E = mc^2$	**C1**
	$E = hc / \lambda$ **or** $E = hf$ **and** $c = f\lambda$	**C1**
	$(1.1 \times 10^{-15}) + (9.11 \times 10^{-31} \times (3.00 \times 10^8)^2) = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / \lambda$ $\lambda = 2.39 \times 10^{-12}$ m	**A1**

Question 8

(a) The majority of the candidates gave the correct textbook or syllabus answer. Some attempted a definition based upon the equation for the de Broglie wavelength. A significant number of candidates specified a particle (commonly an electron) or in a few cases referred to a photon.

(b) Most candidates knew the equation and gave the correct answer.

(c) Most candidates correctly identified a similarity and a difference. A small number of candidates stated a difference as the charges being ‘different’ rather than ‘opposite’, and this was considered to be incomplete as it could refer to the magnitude of the charge and thus be incorrect.

(d) (i) Most candidates gave the correct answer.

(ii) Candidates did not always make it clear that the mass–energy conversion was the origin of the energy of the gamma-ray photons. Some responses incorrectly suggested that the photons were produced in addition to the energy released by the annihilation of the electron–positron pair.

(iii) Most candidates identified conservation of momentum as the reason, but not all of these candidates explained that this was achieved by the photons travelling in opposite directions. A significant number of weaker candidates gave the fact that there were two particles annihilated as the reason for two photons being produced.

(iv) This should have been a straightforward ‘show that’ question using a familiar starting equation for kinetic energy. A significant number of candidates made errors with an incorrect mass or power of ten, or not showing the substituted speed being squared.

(v) Only the strongest candidates recognised that the sum of the kinetic energy and the energy of the mass of the particles was required. Most candidates only gained partial credit for one of the two starting equations.

8(a)	• quantum of energy	**M1**
	• of electromagnetic radiation	**A1**

8(b)(i)	$(\Delta)E = hc / \lambda$	**C1**
	$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (1.96 \times 1.60 \times 10^{-19})$	**C1**
	$= 6.3 \times 10^{-7}\,\text{m}$	**A1**

8(b)(ii)	number per unit time = power / energy per photon $= (1.0 \times 10^{-2}) / (1.96 \times 1.60 \times 10^{-19})$ $= 3.2 \times 10^{16}\,\text{s}^{-1}$	**A1**

8(b)(iii)	*either*: force = rate of change of momentum *or*: $F = \Delta p / t$	**C1**
	$p = E / c$	**C1**
	half the photons have change in momentum p, the other half have change in momentum $2p$	**C1**
	$F = [(1.96 \times 1.60 \times 10^{-19}) / (3.00 \times 10^{8})] \times 3.2 \times 10^{16} \times [(2 + 1) / 2]$ $= 5.0 \times 10^{-11}\,\text{N}$	**A1**

Question 8

(a) The identity of a photon, as a quantum of energy of electromagnetic radiation, was generally well-known, although a significant minority of candidates omitted any reference to energy (as the quantity that is quantised) in their answer.

(b) (i) Generally well-answered, with correct answers being deduced by many candidates.

(ii) The stronger candidates generally calculated the number of photons per unit time, from the power and the photon energy, correctly. A common mistake among some of the weaker candidates was to give an answer that is the reciprocal of the number per unit time. Candidates should consider checking whether their numerical answers have a plausible magnitude to identify errors that have been made during the calculation.

(iii) This was a challenging question. Many candidates successfully got as far as deducing that the average force is equivalent to some multiple of the product of the photon energy and the number of photons per unit time. However, many of the candidates were not able to determine that this multiple had to be 3/2 from the information about half of the photons being absorbed and half of them reflected. Some of the stronger candidates did make this connection, and these candidates generally went on to achieve full credit for the question.

9(a)	diffraction is characteristic of wave behaviour so shows that electrons can behave like waves	**B1**

9(b)	$qV = ½mv^2$	**C1**
	$p = mv$	**C1**
	$p = m \times \sqrt{(2qV / m)}$ $= \sqrt{(2qVm)}$	**A1**

9(c)	(electrons have) greater momentum <u>so</u> smaller (de Broglie) wavelength	**B1**
	fringes become closer together	**B1**

9(d)(i)	straight line with positive gradient	**B1**
	line with positive gradient passing through the origin	**B1**

9(d)(ii)	Planck constant	**B1**

Question 9

(a) Many candidates needed to pay closer attention to the command word for this question. 'Explain' requires more than just a statement. Candidates needed to do two things to gain credit; firstly, to establish that diffraction and interference are characteristic behaviour associated only with waves, and secondly, to conclude from that that the observation provides evidence for the wave nature of moving electrons. Many candidates did the second of these but not the first. Some candidates gave contradictory responses by suggesting that the observation provides evidence for both the wave nature and the particle nature of electrons.

(b) Most candidates were able to obtain credit for the equation $p = mv$. Fewer candidates gave the correct conservation of energy equation $qV = ½mv^2$. The strongest candidates correctly completed the algebra by eliminating v between the two equations to arrive at the correct final answer.

(c) Many candidates realised that the increased momentum of the electrons decreases their de Broglie wavelength, though some found it difficult to make the link. The strongest candidates were able to articulate that the effect of this change on the interference pattern is that the fringe spacing decreases.

(d) Both parts of this question were generally well answered, with many candidates achieving full credit.

8(a)	photoelectric effect	**B1**
8(b)(i)	$E = hf$	**C1**
	work function $= 6.63 \times 10^{-34} \times 8.8 \times 10^{14}$ $= 5.8 \times 10^{-19}$ J	**A1**
8(b)(ii)	$hf = \Phi + ½\, mv_{MAX}^2$	**C1**
	$6.63 \times 10^{-34} \times 11 \times 10^{14} = (5.8 \times 10^{-19}) + (½ \times 9.11 \times 10^{-31} \times v_{MAX}^2)$	**C1**
	$v_{MAX} = 5.7 \times 10^5$ m s^{-1}	**A1**
8(c)	E_{MAX} shown as zero from $f = 8.0$ to 8.8 and non-zero from $f = 8.8$ to 11	**B1**
	all non-zero E_{MAX} shown as a single straight line with a positive gradient	**B1**
	line passing through (11, 1.45)	**B1**

NOT FOUND:

9702_w24_qp_41 EXAMINER REPORT (Qu 8)

8(a)	packet / quantum of <u>energy</u>	**M1**
	of electromagnetic radiation	**A1**

8(b)(i)	electron(s)	**B1**

8(b)(ii)	X labelled – **and** Y labelled +	**B1**

8(c)(i)	0.032 MeV	**A1**

8(c)(ii)	momentum = E / c	**C1**
	momentum $= (0.032 \times 1.60 \times 10^{-13}) / (3.00 \times 10^{8})$ $= 1.7 \times 10^{-23}$ N s	**A1**

8(c)(iii)	$E = hf$ **and** $\lambda = c / f$	**C1**
	$\lambda = hc / E$ $= (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (0.032 \times 1.60 \times 10^{-13})$	**C1**
	$\lambda = 3.9 \times 10^{-11}$ m	**A1**

8(d)	discussion of bone and soft tissue	**B1**
	discussion of different attenuation (coefficients) **or** discussion differences in penetration / transmission / absorption	**B1**
	<u>transmitted intensities</u> (by bone and tissue) are very different (leading to good contrast images)	**B1**

Question 8

(a) This was a straightforward question that was possible to answer by recall. However, where candidates deviated from a learned response, their answer often displayed a fundamental misunderstanding that a photon was a part of, or a component of, electromagnetic radiation. A significant minority did not mention energy at all.

(b) (i) This question was generally well answered, although giving more than one name indicated uncertainty by some candidates.

(ii) Despite correctly identifying electrons as the particles emitted in **(b)(i)**, many candidates then did not appreciate that the anode (and therefore terminal Y) needed to be positive.

(c) (i) Many candidates tried to carry out an unnecessary conversion by applying the charge on an electron to the accelerating voltage. This would seem to indicate a weakness in understanding the use of the electronvolt as an appropriate unit of energy, and further study of this topic might be helpful.

(ii) Stronger candidates were able to utilise the equation $E = pc$ and convert the energy into joules to obtain the maximum photon momentum. The conversion factor was often omitted by many candidates but credit was still gained for the starting equation.

(iii) Either of the two previous answers could have been used by candidates with the appropriate starting equation linking energy or momentum with wavelength. This was sometimes not appreciated, and it was not uncommon to see both methods attempted or combined.

(d) This question produced a broad range of responses. A move from the given phrase ‘body structures’ to identifying actual contrasting mediums in those structures (e.g. bone and soft tissue) achieved credit. However, descriptions were often simplistic, describing ‘stopping’ X-rays, and therefore did not compare two different mediums in the same way (i.e. the greater/lesser absorption properties of each). The strongest answers identified that it was the transmitted intensities that produced the difference in contrast on the film or detector. Weaker answers talked about different ‘blackening’ without an explanation of the cause of any difference.

7(a)	$p = E / c$	**C1**
	$= (3.11 \times 10^{-19}) / (3.00 \times 10^{8})$ $= 1.04 \times 10^{-27}$ N s	**A1**

7(b)(i)	$E = hf$ and $c = f\lambda$ so energy of one photon = hc / λ $350 \times 10^{-3} = N \times (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (640 \times 10^{-9})$	**C1**
	$N = 1.1 \times 10^{18}$	**A1**

7(b)(ii)	F = (change in) momentum / time	**M1**
	Clear use of $p = E / c$ and $t = E / P$ to complete the algebra and arrive at the final equation: e.g. $F = [E / c] / [E / P] = P / c$	**A1**

7(c)(i)	maximum wavelength (of electromagnetic radiation) that causes electrons to be emitted (from surface of metal)	**B1**

7(c)(ii)	work function = $2.26 \times 1.60 \times 10^{-19}$ (J) $E = hc / \lambda$ so $(2.26 \times 1.60 \times 10^{-19}) = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / \lambda_0$	**C1**
	$\lambda_0 = 5.50 \times 10^{-7}$ m	**A1**

NOT FOUND:

9702_m24_qp_42 EXAMINER REPORT (Qu 7)

8(a)	packet / quantum of <u>energy</u>	**M1**
	of electromagnetic radiation	**A1**

8(b)(i)	photoelectric effect	**B1**

8(b)(ii)	• electron needs a minimum energy to escape **or** electron emitted if energy in packet is enough • energy must be absorbed in packets that are related to frequency • intensity relates to number of packets (not to energy in packet) • electron absorbs only a single whole packet *Any three points, 1 mark each*	**B3**

8(c)(i)	Planck constant	**B1**

8(c)(ii)	– work function (energy)	**B1**

Question 8

(a) The identity of a photon as a quantum of energy of electromagnetic radiation was generally well understood.

(b) (i) Many candidates correctly identified the phenomenon described as the photoelectric effect.

(ii) Candidates that read the question and took time to try to answer it had a variety of ways in which credit could be awarded. Many candidates attempted to answer a different question, and either attempted to list the other features of the photoelectric effect that provide evidence for the photon model or repeated the description of what is meant by the threshold frequency that was already contained in the question. These responses could not be awarded credit, so candidates should always be encouraged to check that they are answering the question that has been asked.

(c) A variety of different answers were seen for both parts of this question. Part **(c)(i)** was generally more often correctly answered than **(c)(ii)**. Many candidates did realise that the answer to **(c)(ii)** was an energy, but common incorrect answers were the photon energy and the kinetic energy of the emitted electron.

8(a)(i)	$p = E / c$	**M1**
	$E = hc / \lambda$ and completion of algebra leading to $p = h / \lambda$	**A1**

8(a)(ii)	wavelength = $(6.63 \times 10^{-34}) / (9.5 \times 10^{-28}) = 700 \times 10^{-9}$ m so red	**B1**

8(b)(i)	power = intensity × area	**C1**
	number per unit time = $(160 \times 2.5 \times 10^{-6}) / (9.5 \times 10^{-28} \times 3.00 \times 10^{8}) = 1.4 \times 10^{15}$ s^{-1}	**A1**

8(b)(ii)	pressure = force / area	**C1**
	force = rate of change of momentum $= 2 \times 9.5 \times 10^{-28} \times 1.4 \times 10^{15}$	**C1**
	pressure = $(2 \times 9.5 \times 10^{-28} \times 1.4 \times 10^{15}) / (2.5 \times 10^{-6})$ $= 1.1 \times 10^{-6}$ Pa	**A1**

8(c)	photons have greater momentum **or** fewer photons per unit time	**B1**
	greater photon momentum but smaller number of photons (per unit time) so pressure is the same	**B1**

NOT FOUND:

9702_w23_qp_41 EXAMINER REPORT (Qu 8)

8(a)	transition (emits) (one) photon with energy equal to the difference in energy between the two levels	**B1**
	frequency of radiation corresponds to energy of photon	**B1**

8(b)(i)	line to the left of the pair in Fig. 8.2, labelled A	**B1**
	larger gap between line A and the nearest of the pair in Fig. 8.2 than between the lines in the pair	**B1**

8(b)(ii)	line to the left of both the pair in Fig. 8.2 and line A, labelled B	**B1**
	larger gap between line B and line A than between line A and the nearest one of the pair in Fig. 8.2	**B1**

8(c)	$E = hf$	**C1**
	$E_3 = E_1 + h(f_A + f_B)$	**A1**

Question 8

(a) This question required accurate use of the technical terms energy levels, difference in energy levels, photon energy and radiation frequency. Many responses could not be awarded credit because these terms were not used correctly, often conflating them as all meaning the same thing. Examiners were looking for clear discussion of emitted photon energy as being equal to the difference in energy levels and having a corresponding frequency. Many responses did not have any discussion of photon energy at all, and simply attempted to relate frequency to the energy levels.

(b) Many candidates did not appear to understand what was being asked in this question, and for both **(i)** and **(ii)** drew lines on Fig. 8.1 to represent the transitions rather than the spectral lines on Fig. 8.2 that were asked for.

(c) Most candidates knew the photon energy equation as the starting point, and many of the more able candidates were able to go on to deduce the correct expression.

7(a)	wavelength associated with a <u>moving</u> particle	**B1**

7(b)(i)	(electron) diffraction	**B1**

7(b)(ii)	beam spreads out indicating diffraction **or** light and dark regions indicate an interference pattern	**B1**
	electron beam is behaving as a wave	**B1**

7(c)(i)	central blob and concentric rings	**B1**
	rings closer together (than previously)	**B1**

7(c)(ii)	(greater p.d. so) electrons to have greater momentum	**B1**
	greater momentum so decrease in (de Broglie) wavelength	**B1**
	lower (de Broglie) wavelength (for same grating spacing in crystal) causes: smaller diffraction angle **or** smaller angle of intensity maxima (for each order) **or** decrease in fringe spacing in diffraction pattern	**B1**

Question 7

(a) The definition of de Broglie wavelength is given in the syllabus. Many candidates quoted this correctly but the word ‘moving’ was frequently missing. Another common mistake was for candidates to state a formula, which is not correct in this instance.

(b) (i) The majority of candidates correctly stated electron diffraction here. Some candidates referred to the photoelectric effect, the production of X-rays or other phenomena showing they were not familiar with the diffraction of electrons.

(ii) The question asked candidates what could be concluded from the pattern in Fig. 7.2. To be awarded full credit, candidates had to explain that the pattern was indicating diffraction and go from there to explaining that therefore the electrons must be behaving as waves. Candidates often were given credit for stating that electrons were behaving as waves but very rarely explained the pattern.

(c) (i) A common mistake here was to forget the central dark circle which will always be there no matter what the speed of the electrons.

(ii) Candidates generally realised that an increase in p.d. would lead to a greater electron momentum and hence a shorter de Broglie wavelength, but they did not always explain why that changed the pattern.

7(a)	photon absorbed (by electron) and electron excited	**B1**
	photon energy equal to difference in (energy of two) energy levels	**B1**
	photon energy relates to a single wavelength / single frequency	**B1**
	electron de-excites and emits photon in any direction	**B1**

7(b)	$\frac{hc}{\lambda} = \Delta E$	**C1**
	uses 658 nm	**C1**
	$\frac{6.63\times10^{-34}\times3.00\times10^{8}}{658\times10^{-9}} = -\mathrm{E}_1 - (-3.40 \times 1.60 \times 10^{-19})$ $E_1 = -2.42 \times 10^{-19}$ J	**A1**

Question 7

(a) For descriptive questions, candidates need to be able to use technical language correctly and accurately. For this question, only candidates who correctly discussed the interplay of photons, electrons, photon energies and electron energy levels were able to achieve credit.

(b) Candidates generally struggled with this question. Some candidates were able to use the correct starting equation and/or identify the relevant wavelength. However, only the strongest candidates were able to correctly process the energy change, realising that the sign of the answer must be negative, and that the data requires a 3 significant figure answer.

9(a)(i)	• energy of photon has a corresponding frequency • change in electron energy level emits a single photon • photon energy = difference in energy levels • discrete frequencies must have come from discrete energy gaps • discrete energy changes imply discrete energy levels *Any three points, 1 mark each*	**B3**

9(a)(ii)	transition (to – 3.400 eV) from X corresponds to 658 nm line	**C1**
	$E_1 - E_2 = hc / \lambda$	**C1**
	$E_1 - (-3.400) = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / (658 \times 10^{-9} \times 1.60 \times 10^{-19})$ and so $E_1 = -1.51$ eV (*full substitution and answer needed*)	**A1**

9(b)(i)	redshift	**B1**

9(b)(ii)	moving away (from observer)	**B1**

9(b)(iii)	$\Delta\lambda / \lambda = v / c$ e.g. for 658 nm line: $\Delta\lambda = 686 - 658$ (= 28 nm) (*other lines may be used*)	**C1**
	$28 / 658 = v / (3.00 \times 10^8)$ (*other lines may be used*)	**C1**
	$v = 1.3 \times 10^7$ m s^{-1}	**A1**

9(c)	$v = H_0 d$	**C1**
	$H_0 = (1.3 \times 10^7) / (5.7 \times 10^{24})$ $= 2.3 \times 10^{-18}\ s^{-1}$	**A1**

Question 9

(a) (i) This was another question where many candidates answered a different question from that which was asked. There were many responses that gave answers to questions asking either for a description of the appearance of an emission spectrum or for an explanation of how an emission spectrum is formed, but where candidates did not make a connection between the emission spectrum and the idea of discrete energy levels. There was much confusion between the concepts of photon energy, energy transitions and energy levels, with many responses lacking accuracy in the way these technical terms were used.

(ii) There were many good attempts at this question, with a significant minority of candidates achieving full credit. Those who did identify the correct starting equation and the correct wavelength of the line that corresponds to the transition from level X to the –3.400 eV energy level were usually able to be awarded partial credit, but some candidates were a little confused with working that led to a positive value for the energy of level X. Weaker candidates generally found themselves unable to make a start, with many random attempts to add and subtract the other energy levels to somehow arrive at a value for X.

(b) (i) This question was well answered by most candidates.

(ii) Many candidates correctly identified that the observation shows that the galaxy is moving away from the observer. There was much confusion among weaker candidates between what the observation shows about this galaxy and the extension of such observations into the expansion of the Universe and the Big Bang theory. In particular, the term 'galaxy' was often used incorrectly as if it referred to the 'Universe', with many candidates suggesting that the observation shows that the 'galaxy is expanding'.

(iii) This calculation was well answered by a large proportion of candidates, and many candidates were awarded full credit.

(c) This is another question that was well answered by many candidates. Most candidates who knew the equation for the Hubble constant were usually able to achieve full credit by the error-carried-forward principle even if their answer to **(b)(iii)** was incorrect.

8(a)	photon energy (to remove electron)	**B1**
	minimum energy to remove electron **or** energy to remove electron from surface **or** energy to remove electron with zero kinetic energy	**B1**

8(b)(i)	photon energy = hf	**C1**
	number per unit time = $8.36 \times 10^{-3} / (1.36 \times 10^{15} \times 6.63 \times 10^{-34})$ $= 9.27 \times 10^{15}\ \text{s}^{-1}$	**A1**

8(b)(ii)	$hf = \Phi + E_{\text{MAX}}$	**C1**
	$\Phi = (1.36 \times 10^{15} \times 6.63 \times 10^{-34}) - (3.09 \times 10^{-19})$ $= 5.93 \times 10^{-19}\ \text{J}$	**A1**

8(c)(i)	greater photon energy (and same work function)	**M1**
	so maximum kinetic energy is increased	**A1**

8(c)(ii)	(greater photon energy and same power so) lower number of photons (per unit time)	**M1**
	(each electron absorbs one photon) so lower rate of emission	**A1**

Question 8

(a) Many candidates did not state that the energy was the *photon* energy that was needed to remove the electrons from the surface of the metal.

(b) (i) Many answers here were incorrect due to dividing the maximum kinetic energy of the electrons by the power of the radiation, which produced values that candidates should have realised were not physically realistic.

(ii) There were more correct answers here, but a significant number of candidates used the frequency of the ultraviolet radiation as the threshold frequency and ignored the kinetic energy of the emitted photons.

(c) These two explanations were difficult. Many candidates did not begin with the most fundamental aspect, which was that the photon energy was increased as the frequency of the radiation was increased.