10(a)	recession of galaxy (from observer) causes emitted light to have	**B1**
	increase in <u>observed</u> wavelength / decrease in <u>observed</u> frequency	**B1**

10(b)	(distant) galaxies show redshift <u>so</u> galaxies are moving apart	**B1**
	galaxies moving apart <u>means</u> universe must be expanding	**B1**

10(c)	the speed of recession is proportional to the distance of the galaxies from each other **or** more distant galaxies are receding faster	**B1**
	Any two points from: • more distant galaxies represent further back in time • a long time ago, all matter in the universe must have been very close together • a long time ago, all matter in the universe must have been moving apart very fast	**B2**

Question 10

(a) Many candidates gave incomplete answers, e.g. stating that ‘wavelength’ has increased without adding that this is the observed wavelength of light from a galaxy. Some candidates referred to planets moving away from the observer.

(b) The stronger candidates made the connection that, if all (or most) galaxies are moving away from the observer (or our galaxy), they are moving away from each other, and therefore the universe is expanding. Some candidates referred to planets rather than galaxies, and some to the universe receding rather than expanding.

(c) Many candidates stated Hubble’s law without further explanation. A significant proportion of candidates correctly described that more distant galaxies are receding faster. A common conclusion was that galaxies were closer together in the past, but often candidates did not develop this to the idea that all matter (or contents of the universe) was in a very small space a long time ago, i.e. before the formation of stars and galaxies. This is ultimately the reasoning that supports the Big Bang theory.

9(a)	difference between mass of nucleus and mass of (constituent) nucleons	**M1**
	when nucleons are separated to infinity	**A1**

9(b)	$\Delta m = (2 \times 2.013553) - (4.001505)$ (u) (= 0.025601 u)	**C1**
	$E = c^2\Delta m$	**C1**
	energy from one He-4 nucleus $= 0.025601 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$ $(= 3.82 \times 10^{-12}$ J)	**C1**
	energy to form 1.00 mol $= 3.82 \times 10^{-12} \times 6.02 \times 10^{23}$ $= 2.30 \times 10^{12}$ J	**A1**

9(c)(i)	$L = 1.09 \times 10^{11} \times (3.00 \times 10^8)^2$	**C1**
	$= 9.81 \times 10^{27}$ W	**A1**

9(c)(ii)	$L = 4\pi\sigma r^2 T^4$ $9.81 \times 10^{27} = 4\pi \times 5.67 \times 10^{-8} \times (1.19 \times 10^9)^2 \times T^4$	**C1**
	$T = 9930$ K	**A1**

9(d)	standard candles have known luminosity	**B1**
	radiant flux intensity (from star) measured (on the Earth)	**B1**
	distance found from $F = L / (4\pi d^2)$	**B1**

Question 9

(a) The definition of mass defect seems to be less well known than other definitions. Some candidates appeared to have the right idea but did not use the terminology correctly (particularly with nucleus/nuclei/nuclide/nucleons/neutrons). Many of the candidates that did identify mass defect as the difference in mass between the nucleus and its constituent nucleons did not make the point that the latter mass is when the nucleons are infinitely separated. Common misconceptions among weaker candidates were either that mass defect is a change in mass during a reaction, or that mass defect is an energy.

(b) Many of the more able candidates obtained credit for determining the energy release from the formation of one nucleus of helium, but then stopped short of extending that to one mole.

(c) (i) Most candidates found this question difficult and attempted to use an equation for which the information was not available. The question was a test of their understanding of what is meant by luminosity (as the rate of emission of energy from the star) and they needed to realise that this could be obtained by applying $E = c^2\Delta m$ to the rate of loss of mass.

(ii) Many candidates were able to obtain full credit here using their value for luminosity from **(c)(i)**.

(d) Most candidates made the point that standard candles have known luminosity. The use of the equation $F = L / 4\pi d^2$ to calculate d was also articulated well by many candidates. Many candidates found it difficult to explain the use of the radiant flux intensity (including naming the quantity correctly).

9(a)	temperature inversely proportional to wavelength	**M1**
	temperature is thermodynamic temperature of surface of star **and** wavelength is the wavelength at which maximum emission rate from star occurs	**A1**

9(b)	*Any three points from:* • (surface) temperature of star X = 7000 K **or** star X has a higher temperature than the Sun • star X has a higher luminosity than the Sun • luminosity of star X = 2.7×10^{27} W • radius of star X = 1.3×10^{9} m	**B3**

9(c)	light (from star X) is redshifted	**B1**
	wavelength of peak emission rate would be greater (using observed data)	**B1**

Question 9

(a) The relationship between temperature and wavelength was generally understood. Some candidates omitted reference to the *surface* temperature or did not mention a star or black body.

(b) Many candidates wrote at least one answer that, although factually correct, was not a *conclusion* that could be drawn from the data. Some were simply readings of the data itself, put into words. This would suggest that candidates would benefit from exercises in differentiating between the data itself and the conclusions available from it. Candidates who correctly calculated quantitative answers such as the surface temperature, luminosity or radius of star X needed to include a unit with their answers for credit.

(c) Candidates were more able to identify the visible change to the line in Fig. 9.2 than to identify what was being redshifted to cause the change. A minority of candidates incorrectly described the star as being redshifted.

10(a)	speed is (directly) proportional to distance	**M1**
	speed is speed of recession of galaxy from an observer, and distance is the distance of the galaxy from the observer	**A1**

10(b)(i)	galaxy is receding from the Earth	**B1**
	observed wavelength is redshifted from emitted wavelength	**B1**

10(b)(ii)	$\Delta\lambda / \lambda = v / c$ $(4.91 - 4.62) / 4.62 = v / (3.00 \times 10^8)$	**C1**
	$v = 1.9 \times 10^7\ \text{m s}^{-1}$	**A1**

10(b)(iii)	wavelength (of maximum intensity) is inversely proportional to temperature	**B1**
	observed wavelength too high, so determined temperature too low	**B1**

10(c)	$v = H_0 d$	**C1**
	$d = (1.9 \times 10^7) / (2.3 \times 10^{-18})$ $= 8.3 \times 10^{24}\ \text{m}$	**A1**

Question 10

(a) Most candidates earned partial credit by stating that speed and distance were proportional, but many were not awarded full credit due to muddled details regarding the what the speed and distance referred to. Some candidates referred to ‘celestial bodies’ instead of galaxies (a celestial body could be a planet among other irrelevant objects).

(b) (i) Common errors were failing to clearly identify the observed and emitted wavelengths in comparisons and using wording which suggests that the observed wavelength is continuing to increase.

(ii) Use of the incorrect wavelength as the denominator in the equation prevented some candidates from gaining credit.

(iii) Most candidates gained partial credit by showing that they were aware of the inverse proportionality between wavelength and temperature, but many did not gain full credit due to incomplete statements to justify their conclusion.

(c) Most candidates gave the correct answer, some with the benefit of an error carried forward from **(b)(ii)**.

10(a)(i)	total power of radiation emitted (by the star)	**B1**

10(a)(ii)	standard candle has known luminosity	**B1**
	measure the radiant flux intensity	**B1**
	use $F = L / (4\pi d^2)$ to calculate d	**B1**

10(b)(i)	$v = 2\pi R / T$	**C1**
	$v = 3.00 \times 10^8 \times (656.2877 - 656.2831) / 656.2831$	**C1**
	$R = [3.00 \times 10^8 \times (656.2877 - 656.2831) / 656.2831] \times (2.07 \times 10^6) / 2\pi = 6.93 \times 10^8 \text{m}$	**A1**

10(b)(ii)	Z is moving towards Earth	**M1**
	so observed wavelength is less than the emitted wavelength	**A1**

10(b)(iii)	$L = 4\pi\sigma r^2 T^4$ $3.8 \times 10^{26} = 4\pi \times 5.67 \times 10^{-8} \times (6.93 \times 10^8)^2 \times T^4$	**C1**
	$T = 5800\text{K}$	**A1**

Question 10

(a) (i) Candidates who knew the theory were generally able to give a full definition of luminosity, as the total radiant power of the star. Many responses were partial answers.

(ii) Many full and accurate descriptions were seen in response to this question, which directly assesses the syllabus learning outcome concerning the use of standard candles to determine distances to galaxies. For full credit, candidates needed to establish how the information about luminosity and radiant flux intensity is established, and then how the equation linking them can be used to calculate the distance.

(b) (i) For a relatively challenging 'show that' question, that required various topics within the syllabus to be assembled, this question was well-answered. The candidates that did compile all the relevant physics together, establishing the speed of rotation and the relationship between speed, radius and period, generally received two of the three marks available. For the third mark, all elements of the 'show that' working needed to be present, and there were some common reasons for not meeting the requirements for that mark. One was not showing the working leading to the $\Delta\lambda$ value; one was use of the incorrect wavelength in the Doppler equation; one was omission of the speed of light in the working, and the other was not showing how the period is used in the working. Full credit was achieved by many candidates.

(ii) Many candidates incorrectly asserted that the observed wavelength will be larger due to redshift. The stronger candidates realised that point Z on the Sun is moving towards the observer, and hence the observed wavelength in this situation will be less than the emitted wavelength.

(iii) Generally well-answered.

10(a)	• <u>redshift</u> is the increase in observed wavelength / decrease in observed frequency (caused by Doppler effect) • radiation from distant galaxies is observed to be redshifted • redshift provides evidence that galaxies are moving apart • <u>galaxies</u> moving apart means Universe must be expanding *Any three points, 1 mark each*	**B3**

10(b)(i)	$F = L / 4\pi d^2$	**C1**
	$d = \sqrt{(1.90 \times 10^{36} / [4\pi \times 8.42 \times 10^{-16}])}$ $= 1.34 \times 10^{25}$ m	**A1**

10(b)(ii)	$\Delta\lambda / \lambda = v / c$ $(726 - 658) / 658 = v / (3.00 \times 10^8)$	**C1**
	$v = 3.1 \times 10^7$ m s^{-1}	**A1**

10(c)(i)	line with positive gradient passing through the origin	**B1**
	straight line with positive gradient	**B1**

10(c)(ii)	Hubble constant	**B1**

NOT FOUND:

9702_w24_qp_41 EXAMINER REPORT (Qu 10)

8(a)(i)	movement of star causes change in (observed) frequency **or** movement of star causes redshift	**B1**
	observed frequency is lower (than emitted frequency)	**B1**

8(a)(ii)	all three lines shown to left of corresponding printed lines	**B1**
	distance between drawn line and corresponding printed line approximately the same for all three lines	**B1**

8(b)(i)	$E = hf$ **and** $\lambda = c / f$	**C1**
	$E = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (488 \times 10^{-9})$ $= 4.08 \times 10^{-19}$ J	**A1**

8(b)(ii)	photon energy $= (4.08 \times 10^{-19}) / (1.60 \times 10^{-19})$ $= 2.55$ eV	**C1**
	energy level $= -3.40 + 2.55$ $= -0.85$ eV	**A1**

8(b)(iii)	$\Delta\lambda = \lambda \times (v / c)$ $= (488 \times 6.2 \times 10^{6}) / (3.00 \times 10^{8})$ (= 10 nm)	**C1**
	observed wavelength $= 488 + \Delta\lambda = 488 + 10$ $= 498$ nm	**A1**

8(c)	$v = H_0 d$	**C1**
	$d = (6.2 \times 10^{6}) / (2.3 \times 10^{-18})$ $= 2.7 \times 10^{24}$ m	**A1**

Question 8

(a) (i) This question required candidates to explain that the observed frequency is lower than the emitted frequency because of the redshift caused by the recession of the galaxy. Many candidates struggled to articulate this using the correct technical language, but the more able candidates were usually able to achieve at least partial credit.

(ii) Examiners were expecting to see all three lines shifted to the left by a consistent distance. All three possible mark outcomes were common.

(b) (i) Most candidates knew the correct starting equation, and in many cases the substitution was also correct. Some candidates did not appreciate that the precision of the data requires a three significant figure answer.

(ii) This was a demanding question, and many candidates were able to achieve partial credit for converting the photon energy into eV. Only the strongest candidates appreciated how the photon energy needs to be combined with the –3.40 eV energy level to get to the answer of –0.85 eV.

(iii) Many candidates continued to attempt to use the photon energy equation, apparently unaware that this question is about Doppler shift. Of those that did realise that they needed to use the Doppler shift equation, most successfully calculated the 10 nm value of $\Delta\lambda$, and the majority also went on to correctly add that to the 488 nm figure to get to the answer of 498 nm.

(c) This question involving Hubble’s law was well answered by the majority of candidates.

10(a)(i)	total power	**B1**
	power radiated (by the star)	**B1**
10(a)(ii)	standard candle has known luminosity	**B1**
	radiant flux intensity measured by observer	**B1**
	(distance calculated using) $F = L / 4\pi d^2$	**B1**
10(b)(i)	luminosity $= 4\pi\sigma r^2 T^4$ $= 4\pi \times 5.67 \times 10^{-8} \times (6.96 \times 10^8)^2 \times 5780^4$	**C1**
	$= 3.85 \times 10^{26}$ W	**A1**
10(b)(ii)	$\lambda_{MAX} T$ = constant	**C1**
	temperature $= (5780 \times 501) / 624$ $= 4640$ K	**A1**

Question 10

(a) (i) This was a recall question that was generally answered successfully.

(ii) Many candidates were familiar with the method, starting with a clear explanation of a standard candle and finishing with the correct equation to link luminosity, radiant flux intensity and distance. There was often some confusion shown as to how the radiant flux intensity was arrived at. Weaker answers attempted to combine Doppler shift and Hubble's law with luminosity.

(b) (i) Many candidates correctly applied the Stefan's law equation and calculated a correct final answer including a correct unit. However, some of those did not appreciate that the data were given to three significant figures and the answer could also be given to three significant figures.

(ii) The relationship between the wavelength of peak radiation and temperature was known by many candidates, although it was common for the ratio between the two wavelengths to then be written the wrong way around, yielding an incorrect answer. Some candidates ignored the data provided for the Sun and instead used a remembered value for Wien's constant that did not match the precision of the other data. This resulted in an inaccurate final answer.

10(a)(i)	$L = 4\pi\sigma r^2 T^4$ $3.85 \times 10^{26} = 4\pi \times 5.67 \times 10^{-8} \times r^2 \times 5780^4$	**C1**
	$r = 6.96 \times 10^8$ m	**A1**
10(a)(ii)	$F = L / 4\pi d^2$ $= (3.85 \times 10^{26}) / (4\pi \times (1.50 \times 10^{11})^2)$	**C1**
	$= 1.36 \times 10^3$ W m^{-2}	**A1**
10(a)(iii)	line of same shape showing peak intensity at greater wavelength	**B1**
	line of same shape showing lower peak intensity	**B1**
10(b)(i)	5 lines in same pattern shifted to longer wavelengths	**B1**
10(b)(ii)	$\Delta\lambda / \lambda = v / c$ $\Delta\lambda = (21400 / 300000) \times 656$ $= 46.8$ nm	**C1**
	wavelength $= 656 + 46.8$ $= 703$ nm	**A1**
10(b)(iii)	(peak) wavelength too high so temperature too low	**B1**

NOT FOUND:

9702_m24_qp_42 EXAMINER REPORT (Qu 10)

10(a)	temperature inversely proportional to wavelength	**M1**
	temperature is thermodynamic temperature of surface, and wavelength is the wavelength at which maximum emission rate occurs	**A1**

10(b)(i)	(astronomical) object of known luminosity	**B1**

10(b)(ii)	star / galaxy is moving away from the student	**B1**

10(b)(iii)	one tick placed in correct column in each row: wavelength:	too high	**B1**
	surface temperature:	too low	**B1**
	distance:	unchanged	**B1**
	radius:	too high	**B1**

Question 10

(a) Most candidates knew that Wien's displacement law involves a wavelength being inversely proportional to a temperature, but only the strongest candidates were able to correctly identify what, in the context of Wien's law, is meant by wavelength and temperature. Common mistakes were to describe the wavelength as a 'maximum wavelength' and/or to omit that the temperature is the thermodynamic temperature of a surface.

(b) (i) This question was generally well answered, although a significant minority of candidates attempted to describe what standard candles are used for rather than stating what one is.

(ii) Many candidates described the consequence of redshift on the observed wavelength, rather than explaining the reason why the light is redshifted.

(iii) This question required candidates to think carefully about the calculations and the effect of redshift. All five possible mark outcomes were common.

9(a)	difference between mass of nucleus and (total) mass of nucleons	**M1**
	when infinitely separated	**A1**

9(b)(i)	neutron	**B1**

9(b)(ii)	$E = \Delta m\, c^2$	**C1**
	$\Delta m = (0.030377 - 0.002388 - 0.009105)\text{u}$ $(= 0.018884\text{u})$	**C1**
	energy release = $(0.030377 - 0.002388 - 0.009105) \times 1.66 \times 10^{-27} \times (3.00 \times 10^{8})^2 = 2.8 \times 10^{-12}$ J	**A1**

9(c)(i)	number of atoms per unit time $= (1.4 \times 10^{28}) / (2.8 \times 10^{-12})$ $(= 5.0 \times 10^{39}\ \text{s}^{-1})$	**C1**
	mass of one atom $= 4 \times 1.66 \times 10^{-27}$ or $(4 \times 10^{-3}) / (6.02 \times 10^{23})$ $(= 6.64 \times 10^{-27}\ \text{kg})$	**C1**
	mass per unit time $= 6.64 \times 10^{-27} \times 5.0 \times 10^{39}$ $= 3.3 \times 10^{13}\ \text{kg s}^{-1}$	**A1**

9(c)(ii)	$L = 4\pi\sigma r^2 T^4$ $1.4 \times 10^{28} = 4\pi \times 5.67 \times 10^{-8} \times (2.3 \times 10^{9})^2 \times T^4$	**C1**
	$T = 7800$ K	**A1**

Question 9

(a) The definition of mass defect appears to be not as well known as most definitions, and many candidates did not give a correct answer. Many candidates tried to suggest that it is an energy, and others described it as a change in mass during a nuclear process. Correct use of technical terms is important, and many responses conflated nucleus, nucleons and neutrons by using them as synonymous terms.

(b) (i) Weaker candidates found it difficult to identify particle X as a neutron, but the stronger candidates generally had little difficulty with this.

(ii) Many candidates answered this question well, and full credit was common. As ever with 'show that' questions, candidates should be advised that full credit requires full substitution of all the working. There were some careless errors in transcribing the mass data that resulted in candidates not being awarded credit, and other candidates omitted to show the multiplication by the value of u or the value of c^2.

(c) (i) This was a challenging question. It was not possible to answer just by recalling an equation and plugging numbers into it. The first step required was to appreciate that the luminosity gives the energy released per unit time and the previous question gives the energy released per nucleus. Between these two, the number of nuclei of helium produced per unit time can be determined. The second step was to determine the mass of a helium nucleus in kg. The two steps can then be put together to determine the mass of helium produced per unit time. Weaker candidates found it difficult to know where to start, often just trying to use the Stefan–Boltzmann law inappropriately because the word 'luminosity' was in the question. A significant proportion of the more able candidates gave fully correct answers and could be awarded full credit.

(ii) Candidates generally found this to be a much more straightforward question than the previous one, and many of them were able to use the Stefan–Boltzmann law correctly to determine the correct answer. Partial credit was also common for candidates who substituted all the values correctly into the equation but then made a mistake with the arithmetic.

10(a)	speed is (directly) proportional to distance	**M1**
	speed is speed of recession of galaxy from an observer, and distance is the distance of the galaxy from the observer	**A1**

10(b)	$F = L / (4\pi d^2)$	**C1**
	$= (3.8 \times 10^{31}) / [4\pi \times (1.8 \times 10^{24})^2]$ $= 9.3 \times 10^{-19}$ W m^{-2}	**A1**

10(c)(i)	galaxy is moving away (from the Earth)	**B1**
	wavelength (of light from the galaxy) increased by the Doppler effect / due to redshift	**B1**

10(c)(ii)	$\Delta\lambda / \lambda = v / c$ $v = [(492 - 486) \times 3.00 \times 10^8] / 486$ ($v = 3.7 \times 10^6$ m s^{-1})	**C1**
	$H_0 = v / d$	**C1**
	$= (3.7 \times 10^6) / (1.8 \times 10^{24})$ $= 2.1 \times 10^{-18}$ s^{-1}	**A1**

Question 10

(a) There were many correct responses here. Some candidates mixed up Hubble's law with Wien's displacement law. The idea of velocity being proportional to distance was often known, but many candidates neglected to talk about the velocity being that of an object emitting light (i.e. a galaxy) and that the velocity was recessional. They also sometimes omitted the fact that the distance was from the observer.

(b) Most candidates calculated the correct value for the radiant flux intensity here. Some weaker candidates started from an incorrect formula, and some forgot to square the distance.

(c) (i) Candidates generally realised that the galaxy was moving away from the Earth, but did not always say that the redshift or Doppler effect was causing the increase in the wavelength of the light received on the Earth.

(ii) There were many correct answers to this two-step calculation. However, a large number of candidates used an incorrect wavelength in the denominator of the redshift equation. Some candidates used the value of the speed of light instead of the recessional speed in the Hubble equation.

10(a)	brighter star could be closer (to Earth)	**B1**
	brighter star could have a greater luminosity (in the visible wavelengths)	**B1**

10(b)	object with known luminosity	**B1**

10(c)(i)	$\dfrac{660.9-656.3}{656.3} \approx \dfrac{v}{3.0\times10^{8}}$ leading to 2.1×10^{6} m s^{-1}	**B1**

10(c)(ii)	$v = H_o d$	**C1**
	$d = 2.1\times10^{6} / 2.3\times10^{-18}$ $= 9.1 \times 1023$ m	**A1**

10(c)(iii)	wavelength has increased / light is redshifted	**B1**
	star within galaxy is moving away / receding (from Earth)	**B1**
	Universe is expanding	**B1**

Question 10

(a) Whilst most candidates did realise that the variations in brightness were due to differences in luminosity and in proximity, many were unable to identify which conditions led to the star appearing brighter. For example, different luminosity was stated, rather than higher luminosity.

(b) This was generally well known, though some candidates did not convey the correct meaning, for example 'The luminosity of a known star'. Others gave contradictory responses. Candidates should know that a standard candle is an object that has a particular characteristic. A standard candle is not a luminosity, not a unit and not a measuring device.

(c) (i) Many candidates did use the Doppler equation for light but thought that the larger wavelength and not the smaller one was the unshifted wavelength. Others omitted to show the substitution of the speed of light. 'Show that' questions always require full substitution of values to be shown.

(ii) This calculation was answered well by most candidates.

(iii) Candidates generally answered well. However, some candidates misinterpreted the previously given data and thought the star in the galaxy was moving towards the observer.

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**
	$H_0 = (1.3 \times 10^7) / (5.7 \times 10^{24})$ $= 2.3 \times 10^{-18}\ \mathrm{s^{-1}}$	**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.

9(a)	total power of radiation emitted (by the star)	**B1**

9(b)(i)	$F = L / (4\pi d^2)$	**C1**
	$= 9.86 \times 10^{27} / [4\pi \times (8.14 \times 10^{16})^2]$ $= 1.18 \times 10^{-7}\ \text{W m}^{-2}$	**A1**

9(b)(ii)	$L = 4\pi\sigma r^2 T^4$ $9.86 \times 10^{27} = 4 \times \pi \times 5.67 \times 10^{-8} \times r^2 \times 9830^4$	**C1**
	radius $= 1.22 \times 10^9$ m	**A1**

9(c)	wavelength of peak intensity determined (from spectrum of star)	**B1**
	wavelength of peak intensity from object of known temperature determined	**B1**
	Wien's displacement law used **or** wavelength of peak intensity inversely proportional to temperature	**B1**

Question 9

(a) Candidates need to remember to include all the detail required in this answer, i.e. the total power of radiation emitted. The word ‘total’ was often missed, as well as the idea of emission.

(b) (i) There were many correct calculations here. Some candidates tried to use the expression for luminosity, rather than the one for radiant flux intensity.

(ii) There were many correct answers. There were some errors due to caused by not raising the temperature to the power of 4.

(c) The question asked for a method of determining the temperature of the star, so an explanation of the steps taken was required. Most candidates understood that the answer was related to Wien’s displacement law, but candidates often did not describe how this is used with a star of known temperature and maximum wavelength and then comparing with the maximum intensity wavelength of the star being measured.