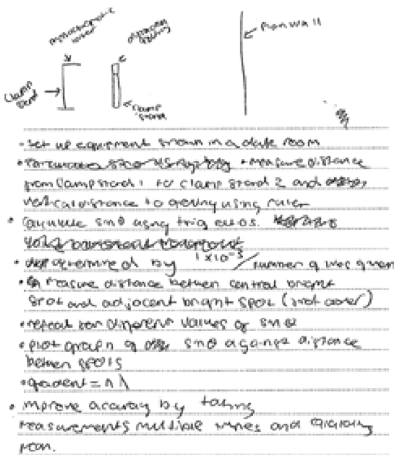
Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		Difference in energy level = 4.84 (× 1^{-19}) (J) $\lambda = hc/4.84 \times 10^{-19}$ and 4.11×10^{-7} (m) seen	M1 A1	Accept (−.58 − (−5.42)) for 4.84 Accept E = hf to find f, followed by $\lambda = c/f = 4.11 \times 10^{-7}$ (m) seen Allow 4.104×10^{-7} (m) seen **Examiner's Comments** As with other 'show that' questions, many candidates understood what to do to find their value of the wavelength, without necessarily showing sufficient evidence of formula re-arrangement.
	b	i	Dark lines are **absorption** lines / idea of photon absorption / idea of electrons absorbing energy / idea of electrons making transition to higher energy level (i.e. excitation) Caused by light passing through (cooler) stellar atmosphere or Earth's atmosphere	B1 B1	Allow (cooler) gases/hydrogen (gas) **Examiner's Comments** Apart from a small number of candidates that confused emission spectra with absorption spectra, it was clear that most candidates recognised that what they needed to do. Technical language skills prevented some otherwise sensible answers from scoring 2 marks.
		ii	$\Delta \lambda/\lambda$ = 22/410 or 21/411 v= 0.054c = 1.6(1) × 10^7 (m s^{-1})	C1 A1	NB 21/411 gives 1.5×10^7 (m s^{-1}) Any evidence of use of 432 as denominator of $\Delta \lambda/\lambda$ is XP zero marks **Examiner's Comments** Most candidates selected the correct formula in this part. If a candidate responded at all, they were likely to score both marks. A small percentage of candidates used the wrong wavelength for the denominator of the relevant expression. This was marked as 'wrong Physics' (XP) on scripts.
		iii	Big Bang / Expanding universe i.e. Hubble's Law / dark matter or dark energy / AW	B1	ignore redshift ignore Doppler **Examiner's Comments**

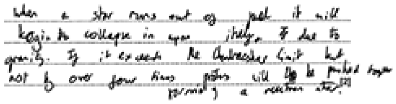
					An overwhelming majority of candidates made some reference to either the Big Bang Theory, cosmological expansion or simply ‘Hubble’s Law’. Some other answers were also given credit as shown in the Mark Scheme although these were very much rarer.
			Total	**7**	
2			**Level 3 (5–6 marks)** description and analysis, with an appropriate comment about accuracy *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Description and some graphical analysis and some comment about accuracy *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Incomplete description or analysis, or an appropriate comment about accuracy *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 mark** *No response or no response worthy of credit.*	B1 × 6	NB - use of two slit interference formula is incorrect physics. Mark XP and treat description as incomplete **Indicative scientific points may include:** **Description** • Angles or distances measured from central maximum • Some method of measuring angle directly, e.g. protractor • Measuring distances from grating to screen and from central maximum to others • Description of maxima • White screen or wall • Recognition and mitigation of risk of injury to eye **Analysis** • Graph of d sin theta against n with gradient lambda (or workable alternative) • Conversion of lines per mm to distance between lines **Accuracy** • Use large room to achieve large distances • Large distance reduces relative uncertainty • Measure distance between corresponding maxima and halve • Use of trigonometry to convert measured distances into angles from the centre • use spots either side of the centre • change diffraction grating for smaller d so that maxima are more spaced out

					• change diffraction grating for larger d so that there are more maxima (and so more points on the graph) • darken the room **<u>Examiner's Comments</u>** This experiment is one of the suggested practicals to complete in the Practical Endorsement. The relevant formula was not on the question paper itself, however it is in the relationships and formulae booklet in the appropriate place. Candidates that described the two-slit interference experiment could not, therefore, be awarded any more than Level 1 (2 marks). As explained in previous series, approaches required a graphical element to find the wavelength (amongst other aspects) in order to achieve Level 2 (4 marks). Finally, a key aspect that distinguished between candidates was their ability to describe and explain the necessary precautions for high quality data. A selection of these is listed in the Mark Scheme. Exemplar 1  Exemplar 1 has satisfied all of the criteria for a Level 3 response, 6 marks. The candidate has described the correct experiment and made it clear how they are going to measure the

					relevant quantities such as the distance of the maxima away from the centre and the distance to the screen so that they can later calculate theta and hence sin(theta). This already is promising for a Level 3 response. The candidate has also completed the analysis correctly by using a graphical approach. It is clear what is going to be plotted on which axis and what the gradient of the line of best fit will represent. Finally, it is clear how the wavelength shall be calculated. The candidate has used trigonometry to calculate theta and has stated that the room should be dark, All of these factors taken together indicate Level 3 thinking.
			Total	**6**	
3	a	i	Estimate of λ_{max} between 440 and 470 nm (T =) 5800 x 500/460 = 6300 K i.e. candidate's value	M1 A1	Allow 2.9 million for 5800 x 500 Allow assumption of 6300 K, calculation of lambda (M1) and then confirmation on graph (A1) for 2 marks **Examiner's Comments** As in previous 'show that' questions, most candidates started this question well by obtaining λmax from the graph and calculating the surface temperature. This was insufficient as a consistent approach to showing working for these questions was applied
		ii	$L = 4\pi r^2 \sigma T^4$ Correct substitution of values i.e. $2.3 \times 10^{29} = 4 \pi r^2 \sigma 6300^4$ radius = $1.4(3) \times 10^{10}$ (m)	C1 C1 A1	**Examiner's Comments** As long as candidates used the equation for Steffan's Law, they tended to score well on this item. There were some candidates that transcribed the power of 4 incorrect yet had ECF applied to their work to score most of the marks available.
	b	i	$P = 7.0 \times 10^{-15} \div 0.11$ $I = 6.36 \times 10^{-14} / 1.0 \times 10^{-4} = 6.4 \times 10^{-10}$ (Wm^{-2})	M1 A1	**Examiner's Comments** Most candidates successfully manipulated the data given to show

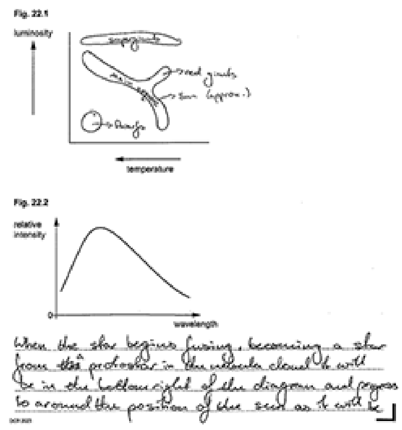
					that the radiant power per unit as required.
		ii	$L/4\pi r^2 = 6.4 \times 10^{-10}$ $r = (L \div (6.4 \times 10^{-10} \times 4\pi))^{0.5}$ $=5.4 \times 10^{18}$ (m) ($\div 9.5\times10^{15}$ =) 560 light years	C1 C1 C1 A1	Allow use of 6×10^{-10} Allow alternative method: Finding intensity at star surface C1 Using ratio of intensities = square of ratio of (star radius / distance to earth) C1 Use of 6×10^{-10} for I gives 580 ly **Examiner's Comments** This is a challenging multi-step question. Essentially it tests understanding of the inverse-square relationship. Some candidates simply used the formula given on the formula sheet. Others did not, however successfully manipulated the data to use the inverse-square rule and/or finding the intensity of radiation leaving the surface of the star. Once the candidate arrived at the distance in metres, it was relatively simple to find the distance in light years.
	c		Any three from: There is a range/ 'band' in the luminosity values at 6300 K range of luminosity is between L. and about 10 L. The uncertainty in the distance calculated = ½ the uncertainty in the luminosity AW Reference to Nu Persei not necessarily being on the main sequence	B1 B1 B1 B1	Check diagram for rewardable content **Examiner's Comments** This item also proved very challenging. The key idea here is that there is a range of luminosities (the inherent power of the star) that correspond to a temperature of 6300 K, not least that the star may not be main sequence at all. These ideas are reminiscent of a question in a previous paper. After those initial ideas, the candidates needed to discuss this more quantitatively by noticing that the range of luminosities was about 10, given that the scale is logarithmic.

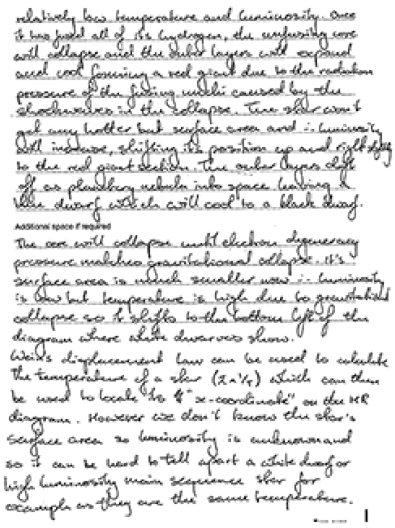
					Assessment for learning There is a lot of Physics relevant to the H-R diagram other than merely the shape of the main sequence and the positions of other classifications of stars. Teachers might consider explaining how the data for the H-R diagram is collected and processed, along with the accompanying uncertainties in those measurements.
			Total	**14**	
4			**B**	1	**Examiner's Comments** The Chandrasekhar limit relates to white dwarf stars and their evolution. Wien's displacement law relates the surface temperature of a star and λ_{max}. The Cosmological principle has nothing to do with stars' velocity in a galaxy, hence the correct answer is B.
			Total	**1**	
5	a	i	• remnant of a (red) super giant star • star can no longer generate (enough) energy by fusion / gravitational force exceeds radiation pressure • formed by (gravitational) collapse / implosion of core (of massive star) **or** gravitational force in core exceeds electron degeneracy pressure • star undergoes a (Type II) supernova (explosion) • core has mass above Chandrasekhar limit / 1.4 x solar mass (and below limit for black hole / 3 solar masses) • (in the core) protons combine with / capture electrons to produce neutrons	B1 x 2	Credit any correct statement, ignoring incorrect statements unless they contradict a previous credited bullet point **Allow** any star with mass greater than 10 solar masses **Allow** star cannot fuse iron without losing energy **Ignore** star runs out of fuel / fusion stops **Examiner's Comments** When describing this process, it is crucial to differentiate between the original supergiant star and its core. The original star must have a mass greater than 10 solar masses, and it is the core of the star that must have a mass greater than the Chandrasekhar limit of 1.4 solar masses. Exemplar 1

					 When a star runs out of fuel it will begin to collapse in upon itself due to gravity. If it exceeds the Chandrasekhar limit but not by over four times protons will be pushed together forming a neutron star. The exemplar above shows a typical response where the original star and the remaining core have not been sufficiently distinguished. **Misconception** It is better to refer to a red supergiant star than to a (super) red giant star, as only supergiant stars are able to end their lives as neutron stars.
		ii	*either:* extremely / very dense *or:* has a very strong gravitational field *or:* supported by neutron degeneracy pressure *or:* fusion is no longer taking place *or:* core has mass above Chandrasekhar limit / 1.4 x solar mass (and below limit for black hole / 3 solar masses)	B1	Credit any correct statement, ignoring incorrect statements unless they contradict a previous credited bullet point **Ignore** references to size / temperature / luminosity / spin / radio waves / composed (mainly/only) of neutrons **Not** high density (must be extremely / very high density) Do not credit this point here if already credited in 3(a)(i) **Examiner's Comments** There were several facts about neutron stars mentioned in the stem of the question which could not receive any credit (such as the fact that they spin and emit radio waves). Many candidates made statements that were too general to receive credit, such as neutron stars are small/hot/bright (but compared to what?) or contain neutrons.
	b	i	number of large squares = 11± 1 no of squares × area of each = 11 x 1 x 10^{-25} = **1.1 × 10^{-24}** (J)	C1 A1	May be inferred from calculation Any valid method allowed (counting squares, trapezium rule, splitting area into regular shapes) **Allow** number of medium squares = 44 ± 4 **Allow** number of small squares = 1100 ± 100

					Allow answers in the range 1.00×10^{-24} to 1.20×10^{-24} **Allow** answer to 1s.f. **<u>Examiner's Comments</u>** Candidates who counted squares underneath the curve almost always got areas with in the allowed range. Those who tried to use trapeziums or other regular shapes were usually less successful.
		ii	300 pc ≈ $300 \times 3.1 \times 10^{16}$ m (= 9.3×10^{18} m) ratio of areas $= \frac{4\pi(300 \times 3.1 \times 10^{16})^2}{3000} = \frac{1.09 \times 10^{39}}{3000}$ (= 3.6×10^{35}) energy = ratio of areas × area under curve = **4.0×10^{11}** (J)	C1 C1 A1	Mark is for working leading to the correct distance. Distance does not need to be seen explicitly but 9.3×10^{18} m implies C1 Mark is for working leading to the correct ratio. Ratio does not need to be calculated but 3.6×10^{35} implies C1 **Allow** calculation of inverse ratio (= 2.8×10^{-36}) **Ignore** unit if one is given Mark is for correct answer; **allow** answer to 1s.f. Answer = 3.6×10^{35} × candidate's answer to 3c(i) **Allow ECF** for incorrect calculation of area / energy in 3c(i) Expect an answer in the range 3.6×10^{11} to 4.4×10^{11} Note: candidates could also calculate the answer by using ratio of energies = ratio of powers or intensity of pulsar = intensity at telescope **<u>Examiner's Comments</u>** This question stretched even the highest ability candidates. The key was in realising that the intensity of the pulsar = the intensity at the telescope. So the ratio of powers (or energies) = ratio of surface areas. Most candidates successfully converted 300 pc into metres.

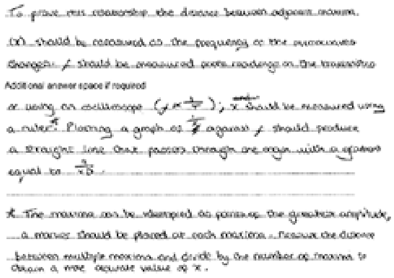
					However, some did not realise that the surface area of a sphere is $4\pi r^2$, a formula that is in the data, formulae and relationships booklet.
			Total	**8**	
6			**Level 3 (5–6 marks)** Clear description, explanation and limitations with correct annotations on diagram *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description of evolution **and** some explanation of analysis or Some description of evolution **and** some limitations *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **or** Limited explanation or limitations *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1 x 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description of evolution** • Main sequence labelled • Red giants/supergiants labelled • White dwarves labelled • Correct order of evolution • Dependence on mass/Chandrasekhar's limit • Evolutionary track shown on diagram **Explanation of analysis** • Identification of peak wavelength from graph • Use of Wien's law • Determination of temperature • Gives the horizontal co-ordinate **Limitations** • Does not give luminosity data • Cannot distinguish between similar temperature stars (e.g. white dwarf, main sequence or a hot super giant) • Need luminosity data to classify the star • Difficult to isolate light from stars in other galaxies to analyse • If looking at stars in other galaxies, have to account for red shift requiring emission data. **<u>Examiner's Comments</u>** Most Level of Response (LoR) questions have multiple parts to them. The first task the candidates are

					asked is to describe the life of a star similar to the Sun with the added complexity of showing or describing how that affects the star's position on the H-R diagram. Many candidates enjoyed considerable success here. Fig 22.2 proved more challenging to interpret. As there are no scales on the axes, it is difficult to say what colour this star is, however λ_{max} is relatively low, which points in the direction of early-mid-life (yellow or yellow white). Candidates rightly suggested that Wien's law was applicable and that as the star grew older and expanded into a red giant, the curve's peak would move to the right. The most challenging aspect of this question is suggesting what limitations this approach has. The lack of scales has already been mentioned. The colour alone cannot uniquely define a star's position on the H-R diagram and thus the stage of life of the star. The graph only gives a relative intensity, which means that the total output of the star, or its luminosity cannot be measured. Exemplar 3 

					 relatively low temperature and luminosity. Once it has fused all of its hydrogen, the unfusing core will collapse and the outer layers will expand and cool forming a red giant due to the radiation pressure of the fusing which caused by the shockwaves in the collapse. The star can't get any hotter but surface area and ∴ luminosity will increase, shifting its position up and right to the red giant section. The outer layers drift off as planetary nebula into space leaving a white dwarf which will cool to a black dwarf. Additional space if required The core will collapse until electron degeneracy pressure matches gravitational collapse. It's surface area is much smaller now ∴ luminosity is low but temperature is high due to gravitational collapse so it shifts to the bottom left of the diagram where white dwarves show. Wein's displacement law can be used to calculate the temperature of a star ($\lambda \propto 1/T$) which can then be used to locate its "x-coordinate" on the HR diagram. However we don't know the star's surface area so luminosity is unknown and so it can be hard to tell apart a white dwarf or high luminosity main sequence star for example as they are the same temperature. 1 This candidate described the life cycle of sun-like stars in great depth, completed an excellent HR diagram and in the text described the path of the star on the H-R diagram throughout its lifetime. The references in the last paragraph are what makes this response worthy of a Level 3. The candidate has answered all aspects of the question, explaining both Wien's law and how the luminosity (and hence position on the H-R diagram) is impossible from the data presented.
			Total	**6**	
7		i	=1 × 0.00097 =1000 parsecs	A1	1030 to 3sf
		ii	$=0.00097 \div 7.5 \times 10^{-3}$ (x100%) =13%	C1 A1	NOT half of the precision here (reference specification) Accept 1 sig fig value 10% Unrounded answer is 12.93... % **<u>Examiner's Comments</u>** The maximum stellar distance is given by the smallest parallax Hipparcos can measure, i.e. 9.7×10^{-4} arcsec. The distance corresponding to this parallax is $1/9.7 \times 10^{-4}$ = 1030 pc. To find the percentage uncertainty in the distance, candidates needed to divide the smallest detectable change in the parallax by the parallax itself. This is equivalent to the percentage uncertainty in the distance because of

					the reciprocal relationship of distance with parallax. Many candidates correctly determined both quantities. A minority of candidates confused the two similar sounding quantities.
			Total	**3**	
8			B	1	
			Total	**1**	
9			C	1	
			Total	**1**	
10			C	1	**<u>Examiner's Comments</u>** The spectrum in the question and those for answers A and B depict emission spectra. Spectra C and D are absorption spectra. The question asks for the absorption spectrum from distant galaxies so only answers C and D could be correct. With the recession velocity of 0.031*c*, both wavelengths will be increased by 3.1 percent. The laboratory wavelength of 434 nm becomes 447 nm after the redshift. The laboratory wavelength of 486 nm becomes 501 nm and so lies outside the range for these diagrams. This makes the correct answer C.
			Total	**1**	
11		i	***Level 3 (5–6 marks)** Clear explanation **and** clear description *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear explanation **or** clear description (but not both) **or** Some explanation **and** some description	B1 × 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Explanation of pattern** • Interference / superposition occurs • Path difference a whole number of wavelengths • means waves are (exactly) in phase (or $\Delta\varphi = 0$) • giving (maximum) constructive interference

			There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence. **Level 1 (1–2 marks)** Limited explanation **or** Limited description *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		• which leads to maximum intensity • Path difference an odd number of half wavelengths (or $\Delta\varphi = \pi$ radians) • means waves are in antiphase • giving (maximum) destructive interference • which leads to minimum intensity **Description of relationship between f and x** • $\lambda = ax/D$ **and** $c = f\lambda \rightarrow x = cD/af$ • so $x \propto 1/f$ (provided a and D remain constant) • Use ruler along QP to measure x (or $10x/10$, say) • Connect oscilloscope to transmitter or detector to measure f • Vary f (keeping a and D constant) and measure corresponding x • Calculate fx which should remain constant • Or plot graph of $1/x$ against f (or x against $1/f$) • Should give straight line <u>through the origin</u> **<u>Examiner's Comments</u>** There were three parts to this LoR question and all needed to be addressed to access the top level. Candidates were first asked to explain why a pattern of maximum and minimum intensity was observed. Marks were given to candidates who used precise scientific wording, e.g. destructive interference occurs when waves are in antiphase (rather than merely out of phase) or when the path difference is an odd number of half wavelengths (rather than merely an odd number of wavelengths). Fewer marks were given to candidates who wrote about waves 'cancelling out' or 'amplitudes subtracting'.

					In the second part, the expected relationship between the frequency *f* and the distance *x* is that *f* and *x* are inversely proportional. Most candidates were able to explain this, either algebraically ($\lambda = ax/D$ and $c = f\lambda$ so $x = cD/af$) or descriptively in terms of the waves overlapping more closely as *f* increased. The third part of the question required an explanation of how to verify this inversely proportional relationship. The question stated that the frequency *f* of the microwaves could be adjusted. So the experimental procedure involved varying *f* and measuring *x* (over several maxima for accuracy). If a graph of *f* against *1/x* gives a straight line through the origin then the relationship is verified. Exemplar 3  The exemplar above shows a successful response for the third part of the question. It makes it clear what to vary, what to measure, what measuring instruments to use, and what to do graphically with the results. **Assessment for learning** Only use the words node and antinode in the context of stationary waves.
		ii	At 90° rotation, (interference) pattern disappears At 180° rotation, intensities are the same as at 0° but the maximum/minimum positions are switched / reversed Waves with polarisations at 90° to	B1 B1 B1	**Allow** constant intensity along PQ **Not** zero intensity along PQ **Allow** <u>from 0 to 90°</u> the intensities of the maxima decrease (and the minimum intensities increase) **Allow** <u>from 90 ° to 180 °</u> the intensities of the maxima increase

			each other do not interfere / only waves with same polarisation interfere / only waves with a component in the same plane interfere		(and the minimum intensities decrease) but the maximum/minimum positions are switched / reversed from between 0 and 90° **Allow** waves must <u>oscillate</u> in same plane to interfere **Ignore** at 90° rotation, only waves from Y are detected at D because D can only detect vertical polarised waves **<u>Examiner's Comments</u>** This question was misread by many candidates, who described the variation in *overall* intensity instead of the variation in the *interference pattern*. Some candidates thought that transmitter **X** was rotating away from **Y**, rather than about the **AB** axis. Only a few candidates correctly explained the change in pattern in terms of the change in the amount of interference between the waves from **X** and **Y**. Many said detector **D** was receiving less of a signal from **X**, rather than interference was lessening because of a reduction in the vertical component from **X**.
			Total	**9**	
12	a		Any two points from • (During / shortly after) the Big Bang **or** (Universe was initially) very hot **or** (Universe was initially) gamma photons • Universe expanded **or** Universe cooled (to 2.7K) • wavelength of (gamma) photons subsequently increased	B1 × 2	**Allow** radiation for photons throughout **Allow** cosmos / space for Universe but **not** matter / everything **Allow** frequency/energy of photons subsequently decreased **Allow** wavelength of photons/radiation has redshifted **Allow** wavelength of photons has stretched **<u>Examiner's Comments</u>** Most candidates knew that the microwave background radiation originated in the Big Bang, although one common misconception was that it formed as microwaves which then spread through space. A few candidates thought that it came from

					black holes or supernovas. Precision in scientific language was important here. The photons themselves have not expanded or cooled since the Big Bang, and it is their <u>wavelength</u> that has increased / stretched / been red-shifted.
	b	i	$\lambda_{max} \propto 1/T$ (T has decreased over time so in the past) the <u>peak</u> was at a shorter wavelength / further to the left on the graph	B1 B1	**Not** $\lambda_{max} = 1/T$ May be inferred from candidate's diagram **Ignore** overall shape of spectrum **<u>Examiner's Comments</u>** The mention of Wien's displacement law gave a clue that it would be useful in answering the question. A mark was given for stating the law. Note that the law is $\lambda_{MAX} \propto 1/T$ rather than $\lambda \propto 1/T$ or $\lambda_{MAX} = 1/T$. Candidates who did not draw on the diagram to illustrate their response sometimes missed the second B1 mark because they said that the wavelength (rather than the <u>peak</u> wavelength) would have been smaller. If an examiner says, 'You may draw on the diagram', it is generally a beneficial approach.
		ii	$E\left(=\frac{hc}{\lambda}\right)=\frac{6.63\times10^{-34}\times3\times10^{8}}{1.1\times10^{-3}}$ $E = 1.8 \times 10^{-22}$(J)	C1 A1	Full substitution needed if judging explicitly **<u>Examiner's Comments</u>** This was a straightforward question and most candidates correctly chose and applied the formula $E=\frac{hc}{\lambda}$ **Common problems in 4(b)(ii)** • not converting mm to m • trying to convert the answer to or from MeV
•		iii	**EITHER** $\frac{3\times10^{-6}}{1.8\times10^{-22}}$ **or** 1.66×10^{16} (photons m^{-2} s^{-1}) **OR** $3 \times 10^{-6} \times (150 \times 10^{-4})$ **or** 4.5×10^{-8} (W)	C1	**Allow** 2×10^{14} (s^{-1}) or 3×10^{14} (s^{-1}) Expect to see $1.66 \times 10^{16} \times 150 \times 10^{-4}$ **or** $\frac{4.5\times10^{-8}}{1.8\times10^{-22}}$ **<u>Examiner's Comments</u>** This is a complex, multi-stage

			number of photons per second $\left(= \frac{3 \times 10^{-6} \times 150 \times 10^{-4}}{1.8 \times 10^{-22}}\right)$ $= 2.5 \times 10^{14}$ (s^{-1})	A1	calculation. A good approach was to use: number of photons per second × energy of each photon = amount of energy per second = power = intensity × area The total intensity of the microwave background radiation was given at the start of the question as 3×10^{-6} Wm^{-2}. Converting cm^2 into m^2 proved difficult for many.
		iv	$E = Pt = IAt$ and $V = Ah$ where A is CSA of cylindrical tank and h is height of tank $\Delta\theta = \frac{E}{mc} = \frac{IAt}{\rho A h c} = \frac{It}{\rho hc}$ and so $\frac{\Delta\theta}{t} = \frac{I}{\rho hc}$ $E = mc\theta$ **and** $m = \pi\rho V$ max temp rise s^{-1} $\left(= \frac{\Delta\theta}{t}\right) = \frac{3 \times 10^{-6}}{1000 \times 5 \times 4200}$ max temp rise $s^{-1} = 1 \times 10^{-13}$ (°C s^{-1})	C1 C1 A1	**Allow** nonstandard letters as long as meaning is clear **Allow** 1000 (kg m^{-3}) for ρ **Allow** $\pi r^2 h$ or $5\pi r^2$ for V **Allow** answer to more than 1s.f. (1.43×10^{-13} (°C s^{-1})) **<u>Examiner's Comments</u>** This too was a complex, multi-stage calculation. Most candidates correctly found their way into the question by writing down the formula $E = mc\Delta\theta$ and realising that they needed to use the formula $\rho = m/V$ in order to calculate the mass. The volume V of the cylindrical tank could be found using V = depth × cross-sectional area. However, although the depth was specified in the question, the cross-sectional area was not. Successful candidates realised that, if the cross-sectional area was not given, then it must cancel out later in the calculation. Some used algebra and called the cross-sectional area A. Others simply made up a value for A ($A = 1$ m^2 is the easiest).
			Total	**11**	
13	a	i	(diameter =) $6.4 \times 3.1 \times 10^{16}$ **or** 2.0×10^{17} (m)	C1	**Allow** (radius =) $3.2 \times 3.1 \times 10^{16}$ **or** 9.9×10^{16} (m) **<u>Examiner's Comments</u>**

			(volume =) $4/3\,\pi \times (9.9 \times 10^{16})^3$ (volume =) 4.1×10^{51} (m^3)	C1 A0	Candidates successfully converted the radius from parsecs into metres and from there the volume of the nebula.
		ii	$(E = \frac{3}{2}kT)\ \frac{3}{2} \times 1.38 \times 10^{-23} \times 250$ **or** 5.2×10^{-21} (J) (N =) $1.0 \times 10^{12} \times 4.1 \times 10^{51}$ **or** 4.1×10^{63} ($E_k = 4.1 \times 10^{63} \times 5.2 \times 10^{-21}$) $E_k = 2.1 \times 10^{43}$ (J)	C1 C1 A1	**<u>Examiner's Comments</u>** This brief yet multi-stage question proved relatively challenging. The correct approach here was to find the average kinetic energy of a single particle (using Ek = 3/2 kT) and then multiplying this by the number of particles in the nebula. The number of particles in the nebula was found by multiplying the number density by the volume of the nebula.
	b	i	Mass is proportional to volume **or** diameter^3 **or** radius^3 or $(\frac{6.4}{3})^3$ or $(\frac{3.2}{1.5})^3$ ratio = 9.7	C1 A1	**Allow** attempt at calculating volume of second nebula and comparing volumes directly **Allow** 9.76 (if volume divided by volume of Sun's nebula) **<u>Examiner's Comments</u>** Candidates used several different approaches here. By assuming a similar density, the mass is directly proportional to the volume. Some candidates calculated the volume of the Sun's nebula. Others correctly assumed that the volume and hence mass of each nebula was directly proportional to the diameter^3 (or radius^3).
		ii	Fuel (hydrogen) runs out Super red giant star (Mass of core > Chandrasekhar limit /1.4 therefore) supernova neutron star or black hole (formed)	B1 B1 × 3	**Note: incorrect order is CON** **Allow** alternative route: Red giant formed (mass of star< 10 solar masses, therefore) planetary nebula (and) white dwarf formed **<u>Examiner's Comments</u>** Some candidates used the ratio from the previous part of the question to assume that the star from nebula X would eventually become a white dwarf, as suggested in one of the endorsed textbooks. Others used the

					information in the question, i.e. that the mass of nebula X was far greater than that of the Sun. This meant they were justified in assuming that this particular star would become a supernova. Both approaches were acceptable, provided the candidate chose one route and described it correctly.
			Total	**11**	
14	a		(%) uncertainty of *T* will be 4 times as significant as the uncertainty of *L* Should improve measurements leading to *T*	M1 A1	**Allow** reference to <u>4</u>th power of T **Allow** comparison of $L^{(-)1/2}$ and T^2 <u>**Examiner's Comments**</u> As there is a choice of only two variables here, the first mark was necessarily a 'method' mark. The best answers stated that Stefan's law uses T^4 and so the percentage uncertainty in T would be 4 times more significant (as described in the practical guidance). **OCR support** Teachers and students all have access to the Practical Skills handbook which includes techniques and ideas that prove useful in answering Level of Response and other questions that check practical experience.
	b		***Level 3 (5–6 marks)** Clear description of method and analysis of data **and** correct explanation. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description of method **and** analysis of data **or** explanation. *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.*	B1 × 6	**Indicative scientific points may include**: **Description of method** • Equation using lg of both sides • Use of the lg $X^b = b$ lg X • Comparison with $y = mx$ (+ c) • (y-intercept = 0) **Analysis of data** • Straight line through the origin • Gradient of the graph is b • Gradient calculated to be between 3 and 4 **Explanation**

			Level 1 (1–2 marks) Limited description **or** Limited analysis **or** Limited explanation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		• Labelled sketch of HR diagram • Reference to Stefan's Law • Hotter stars (than the Sun) have greater luminosity (ratio) / luminosity ratio >1 • Hotter stars have much smaller mass ratio than luminosity ratio • Use of data (e.g luminosity of ×10,000 means mass of about ×14) • **therefore** hotter stars lose mass at a much higher rate (compared to their mass) • **therefore** hotter star lifespans are very much shorter than cooler stars **<u>Examiner's Comments</u>** This question relied on a small number of different skills. At first the candidate needed to understand how to find the constant '*b*' and be able to communicate that. Comparison with '$y = mx + c$' invariably helps with this task. Once '*b*' was determined, most candidates didn't refer to it in the rest of their argument, limiting themselves to a Level 2 response. Instead, they talked about features of the HR diagram rather than focusing on the relevance of '*b*'. '*b*' is important because it makes it clear that a small increase in mass gives a much larger increase in luminosity. Luminosity is related to the mass loss per second so a larger luminosity means the mass of hydrogen will 'run out' far quicker in comparison to a larger star.
			Total	**8**	
15			Gravitational force	B1	**Allow** 'gravity' **<u>Examiner's Comments</u>** Most candidates mentioned a word that showed they knew the collapse was to do with gravitational self-attraction.

			Total	**1**	
16			**A**	1	**<u>Examiner's Comments</u>** Approximately half of all candidates chose option B, possibly because they missed the idea of photon absorption in the question. The correct answer is A, because the electron is going up the energy scale.
			Total	**1**	
17			**D**	1	**<u>Examiner's Comments</u>** Candidates found this question challenging because it joins two ideas together. The first idea is that of the Doppler effect on waves from a moving source, which will increase the wavelength received by the observer. This removes options A and B. Once the new wavelength has been calculated, the corresponding angle should be calculated from the diffraction grating equation. It is worth mentioning that the correct answer and the most likely incorrect answer are too close together for the candidate to merely guess.
			Total	**1**	
18			**C**	1	
			Total	**1**	
19			**B**	1	
			Total	**1**	