

WJEC A-LEVEL PHYSICS • UNIT 1

PHYSICS



EXAM QUESTION PACK

1.6 USING RADIATION TO INVESTIGATE STARS

SCORE

/

PERCENTAGE

%

STEMUP

These questions belong to WJEC, not to us.

The examination questions, mark schemes and examiner comments in this pack were written and published by WJEC. They are past assessment materials, reproduced here so that students can revise from them.

What we do not own

STEMUP is not affiliated with WJEC and does not own, and makes no claim to own, any of the question, mark scheme or examiner report material in this pack. WJEC has not endorsed, approved or been involved in the production of it. WJEC and the qualification titles used here belong to their respective owners and appear for identification only.

Where to find the originals

WJEC publishes its past papers, mark schemes and examiner reports free of charge. Always check the current specification at wjec.co.uk before you revise, because content and wording can change between series.

If you hold the rights to any material in this pack and would like it amended or removed, contact admin@stemup.co.uk and we will act on it.

1.

- (a) (i) The spectrum of the star *Rigel* in the constellation *Orion* peaks at a wavelength of 260 nm. Calculate the temperature of the surface of Rigel. [2]

.....

.....

.....

- (ii) What assumption were you making about the way the star's surface radiates? [1]

.....

- (b) To a good approximation the Kelvin temperature of Rigel's surface is twice that of the Sun, and the **radius** of Rigel is 70 times the radius of the Sun. Use *Stefan's Law* to estimate the ratio

$$\frac{\text{total power of electromagnetic radiation emitted by Rigel}}{\text{total power of electromagnetic radiation emitted by the Sun}} . \quad [3]$$

.....

.....

.....

.....

.....

- (c) We can discover the presence of particular atoms in the atmosphere of a star by measuring the wavelengths of dark lines in the star's spectrum.

Explain how the lines arise, and why they occur at specific wavelengths. [3]

.....

.....

.....

.....

4. (a) Stefan's law can be written as:

$$P = A\sigma T^4$$

Show that Stefan's constant, σ , has the base SI units of $\text{kg s}^{-3} \text{K}^{-4}$.

[3]

.....

.....

.....

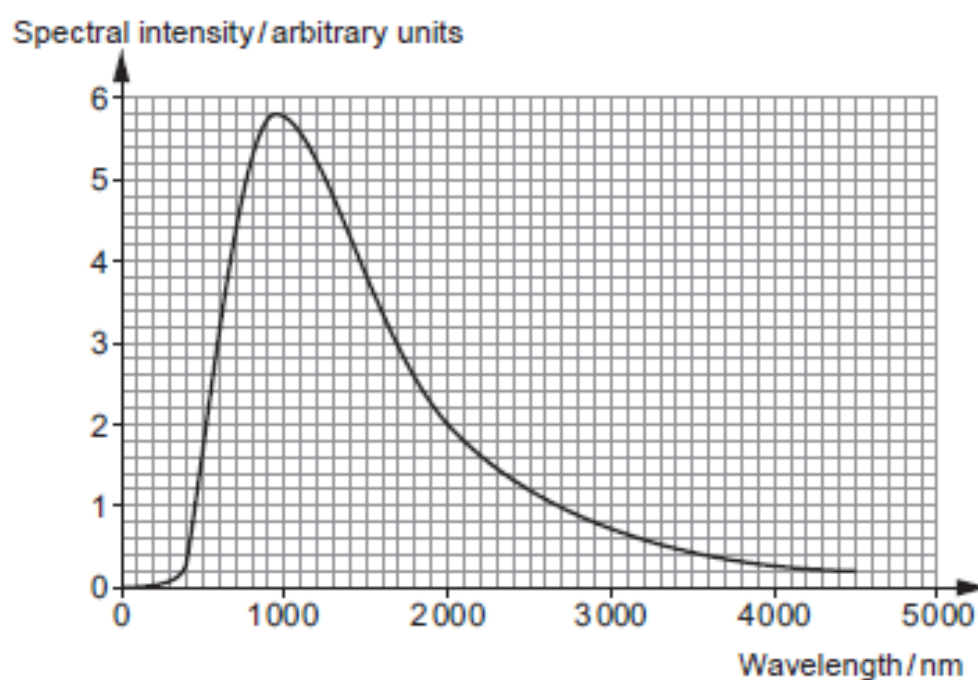
.....

.....

.....

.....

- (b) Our nearest star is called Proxima Centauri. The following graph shows its spectrum.



- (i) The total power output of electromagnetic radiation emitted from Proxima Centauri is 5.9×10^{23} W. Use this information and the graph opposite to calculate its effective diameter. [4]

.....

.....

.....

.....

.....

.....

.....

- (ii) State what colour you would expect Proxima Centauri to appear and name the region of the electromagnetic spectrum in which most of the star's power is radiated. [1]

.....

.....

8. Read through the following article carefully.

Paragraph

A little bit of information about stars by Ignasi Lluís Marxuach

Figure 1 shows the three different routes for the life cycle of different sized stars, from small stars, through medium (Sun-like) stars to explosive high mass stars. For some reason, exam boards tend to ignore the smallest category of stars (red dwarfs) because their cores never become hot enough to produce red giant stars.

1

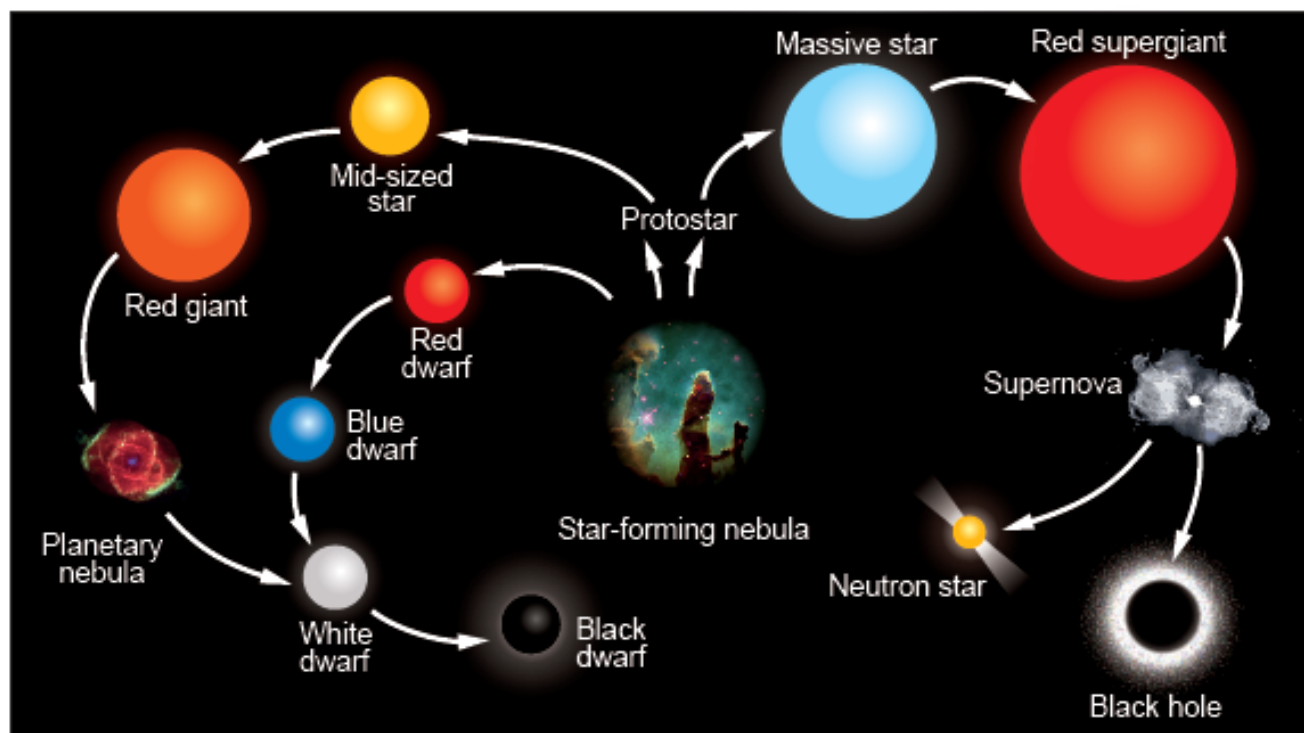


Figure 1

Stars are formed from the gravitational collapse of gas clouds called *nebulae*. Gravitational potential energy is converted to internal energy of hot gases which then emit radiation. This means that the search for new stars usually involves the use of infra-red telescopes in space.

2

The images on the next page show the same gas clouds but the image on the right (Figure 3) is taken with visible light while the image on the left (Figure 2) is taken with infra-red. Notice how the gas clouds are transparent to infra-red so that stars behind the gas clouds become visible at infra-red wavelengths. The areas where stars are forming are those areas of the gas cloud that appear to be emitting radiation at both infra-red and visible wavelengths.

3



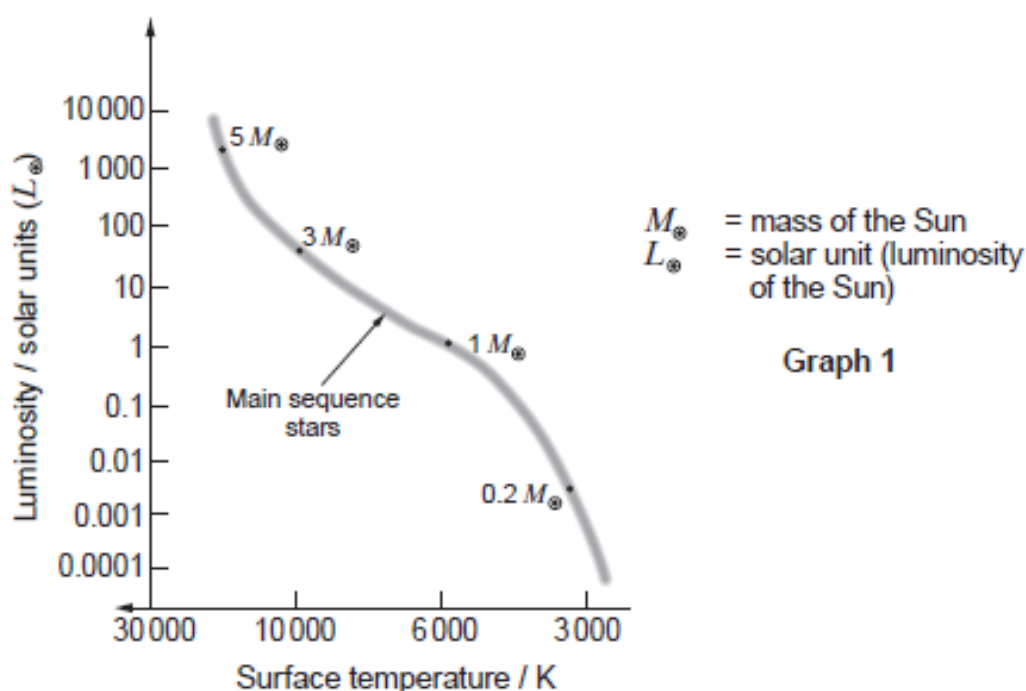
Figure 2 (infra-red image)



Figure 3 (visible light image)

Once the core of a young star is hot enough to initiate hydrogen fusion it is called a *main sequence star*. Such stars are stable, lasting for millions or billions of years and account for around 90% of all stars. They are stable because the outward pressures due to hot gases and electromagnetic radiation are balanced by the inward pressure due to gravity. Larger main sequence stars have denser cores which means that the rate of fusion and the temperature are also greater. A graph of luminosity against temperature for main sequence stars is rather useful, although slightly less useful than it should be because astronomers, apparently, don't realise that values should increase going to the right on normal graphs.

4



Notice that nearly all main sequence stars have surface temperatures in the range 3000K to 20000K. This makes them suitable for analysing using visible light.

5

Another thing to note from the luminosity against surface temperature graph is that these factors seem to depend on the mass of the star. It turns out that there is only one factor that determines a star's position on the graph – its mass. The relationship between mass and luminosity for a star is quite complicated and comes in four parts. 6

$$L = 0.23 M^{2.3} \quad \text{for} \quad M < 0.43 \quad \text{Equation 1}$$

$$L = M^4 \quad \text{for} \quad 0.43 < M < 2 \quad \text{Equation 2}$$

$$L = 1.5 M^{3.5} \quad \text{for} \quad 2 < M < 20 \quad \text{Equation 3}$$

$$L = 3200 M \quad \text{for} \quad M > 20 \quad \text{Equation 4}$$

Note that these equations have been simplified by having the mass of the star (M) in units of the solar mass ($M_{\odot}$), and luminosity in units of the solar luminosity ($L_{\odot}$).

These relationships are rather useful and should explain why large mass stars can be found more easily using ultraviolet telescopes, but they can do so much more when combined with Einstein's equation. 7

$$E = \Delta mc^2 \quad \text{Equation 5}$$

You might, in the first instance, be excused for thinking that a $10 M_{\odot}$ star will burn 10 times longer than the Sun. This, however, could not be further from the truth. Use of Equation 3 should tell you that a $10 M_{\odot}$ star will burn approximately 5000 times brighter. By using Einstein's equation and making a few simplifying assumptions, we find the expected lifetime of a $10 M_{\odot}$ star to be, in fact, approximately 500 times less than that of the Sun. Some might say that a large star "burns the candle at both ends" but it's more accurate to say that it burns the candle at 5000 ends simultaneously. 8

It should be reasonably clear that there is a negative correlation between the mass of a star and its lifetime. Another two star variables that are (bizarrely) negatively correlated are the mass of a white dwarf and its radius. However, that is a completely different story which is beyond the remit of this 2019 Space Odyssey. 9

Answer the following questions in your own words. Extended quotes from the original article will not be awarded marks.

- (a) Write down the complete life cycle of a mid-sized star (see Figure 1). [1]

Star-
forming
nebula →

- (b) Suggest an advantage of placing telescopes *in space* to observe new stars (see Paragraph 2). [1]

.....

.....

.....

- (c) In Figure 2 or 3 below, mark with an X one area where new stars are forming (see Paragraph 3 and Figures 2 & 3). [1]



Figure 2 (infra-red image)



Figure 3 (visible light image)

- (d) Explain, using Newton's 2nd law, how electromagnetic radiation exerts pressure inside a main sequence star (see Paragraph 4). [3]

.....

.....

.....

.....

.....

- (e) Explain why a more massive star has a higher density in its core and why this leads to a higher temperature (see Paragraph 4). [3]

.....

.....

.....

.....

.....

- (f) (i) Show that the wavelength of maximum emission for the hottest main sequence stars is approximately 150 nm (see Paragraph 5 or Graph 1). [2]

.....

.....

.....

.....

- (ii) Discuss whether or not it is appropriate to analyse the hottest main sequence stars using visible light when their wavelength of maximum emission is 150 nm (see Paragraph 5). [2]

.....

.....

.....

.....

- (g) Determine whether or not the star of mass $0.2 M_{\odot}$ is plotted at approximately the correct luminosity in Graph 1 (see Equations 1–4 and Graph 1). [2]

.....

.....

.....

.....

.....

- (h) Explain why a $10 M_{\odot}$ star has a lifetime that is 500 times shorter than that of the Sun, including any simplifying assumptions (see Paragraph 8 and Equations 1–5). [4]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (i) Explain briefly what the author means when he states that a white dwarf's mass and radius are negatively correlated (see Paragraph 9). [1]

.....

.....

.....

4. (a) Define a black body. [1]

.....

.....

.....

- (b) A physics student, Tony, notices that the classroom is warmer when it has a number of students in it rather than when it is empty. Tony claims that each student will behave like a perfect black body and will emit about the same amount of heat as a 200W light bulb. Assuming a typical human body has a surface area of 2 m^2 . Evaluate whether or not Tony appears to be correct. Normal body temperature can be taken to be 37°C . [3]

.....

.....

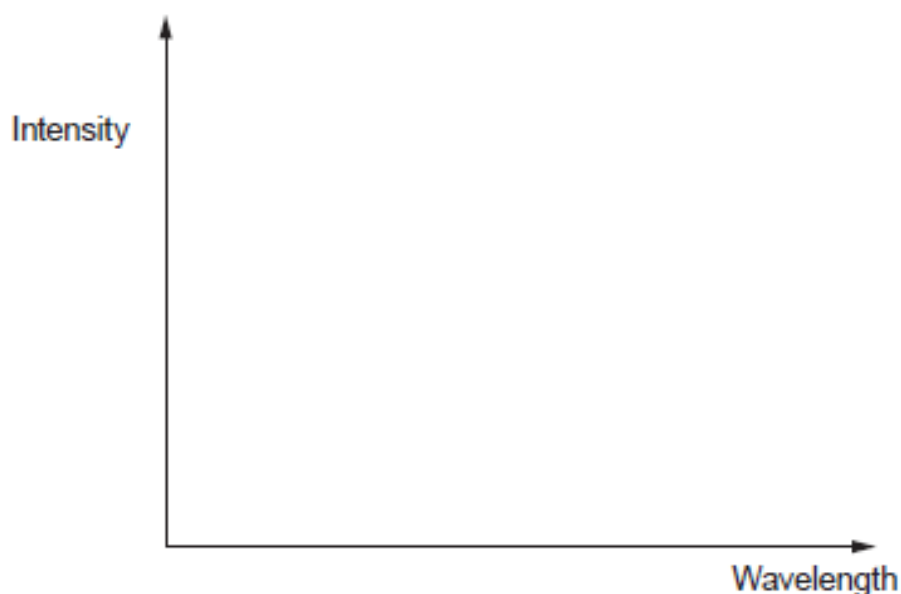
.....

.....

.....

.....

- (c) (i) Some stars appear to be coloured to the naked eye. For two stars of similar diameter one appears red and the other appears blue. Sketch and label typical black body spectra for each star on the graph below. [3]



(ii) Suggest why it is that no stars appear to be green in colour.

[2]

.....

.....

.....

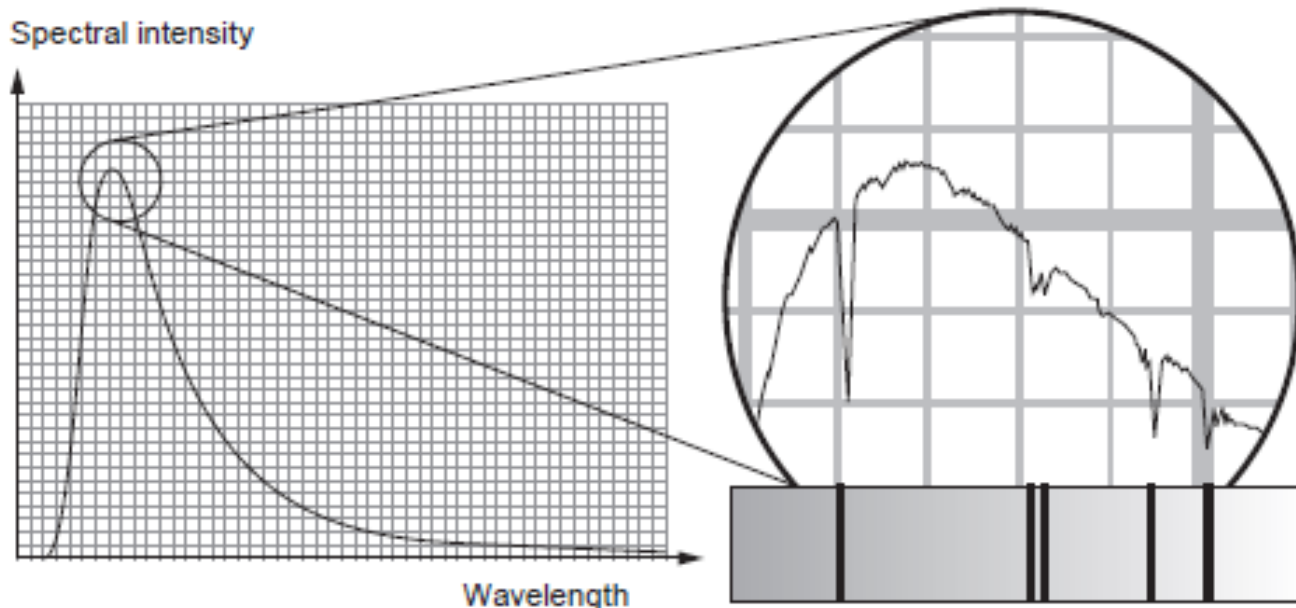
.....

.....

.....

.....

5. 6. (a) A blackbody graph of spectral intensity against wavelength for a star is shown. A magnified section, showing the finer detail of the spectrum is also given. An associated line spectrum is also shown.



Explain how the graph and the spectra can be used to provide information about the star and the elements from which it is made. [6 QER]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (b) (i) Altair is the brightest star in the Aquila constellation. It is 1.58×10^{17} m away, and the intensity of its electromagnetic radiation reaching the Earth is $1.32 \times 10^{-8} \text{ W m}^{-2}$. Show that its luminosity is approximately $4 \times 10^{27} \text{ W}$. [3]

.....

.....

.....

.....

.....

.....

- (ii) Calculate Altair's diameter given that its surface temperature is 7 700 K. [3]

.....

.....

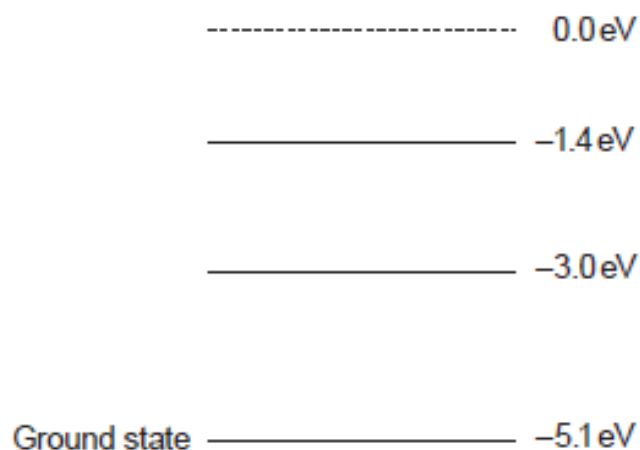
.....

.....

.....

.....

6. The diagram shows three energy levels of a sodium atom.

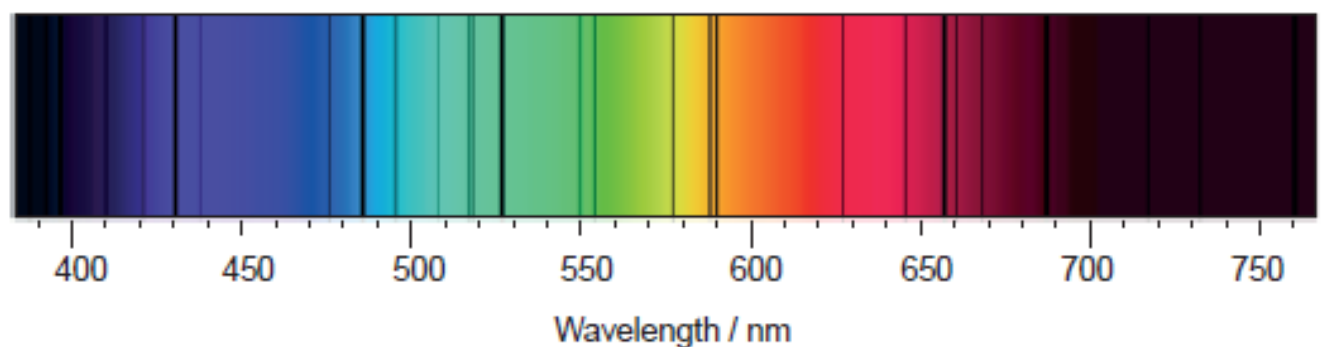


(a) State the ionisation energy of a sodium atom.

[1]

(b) White light passes through a cloud of sodium atoms. The light which emerges is found to have the continuous spectrum of white light but with dark lines crossing the spectrum. State briefly how the dark lines are caused and what happens to the atoms in the process. [3]

- (c) (i) The spectrum of a star is shown below. The wavelength of one of the dark lines is 590 nm. Evaluate whether this is evidence for the presence of sodium in the star. [3]



.....

.....

.....

.....

.....

.....

- (ii) The wavelength of peak emission of the star is 100 nm. Determine its surface temperature. [3]

.....

.....

.....

.....

.....

.....

7.

7. (a) Describe the main features of the spectrum of a star and state where in the star they arise. [2]

.....

.....

.....

.....

.....

- (b) The table gives some information about two stars.

Star	Luminosity / W	Distance from Earth / m
Sirius	9.7×10^{27}	8.1×10^{16}
Vega	1.5×10^{28}	2.4×10^{17}

- (i) Determine the ratio:

$$\frac{\text{Intensity of radiation reaching Earth from Sirius}}{\text{Intensity of radiation reaching Earth from Vega}}$$

[3]

.....

.....

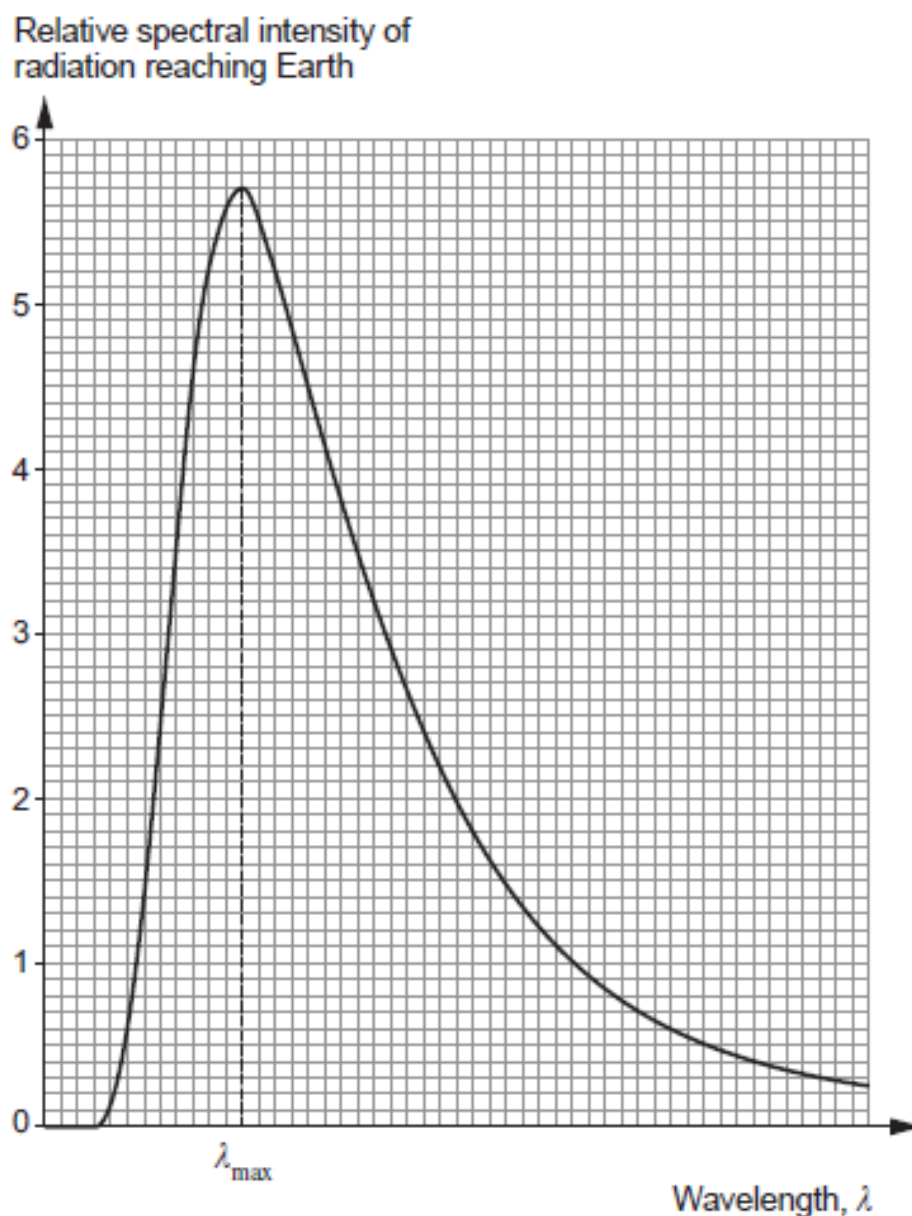
.....

.....

.....

.....

- (ii) The two stars have similar surface temperatures. Below is a black body radiation curve for Sirius. Using your answer to (b)(i), sketch the expected black body curve for Vega on the same axes. [2]



- (iii) Determine λ_{max} , given that the surface area of Sirius is $1.8 \times 10^{19} \text{ m}^2$. [4]

.....

.....

.....

.....

.....

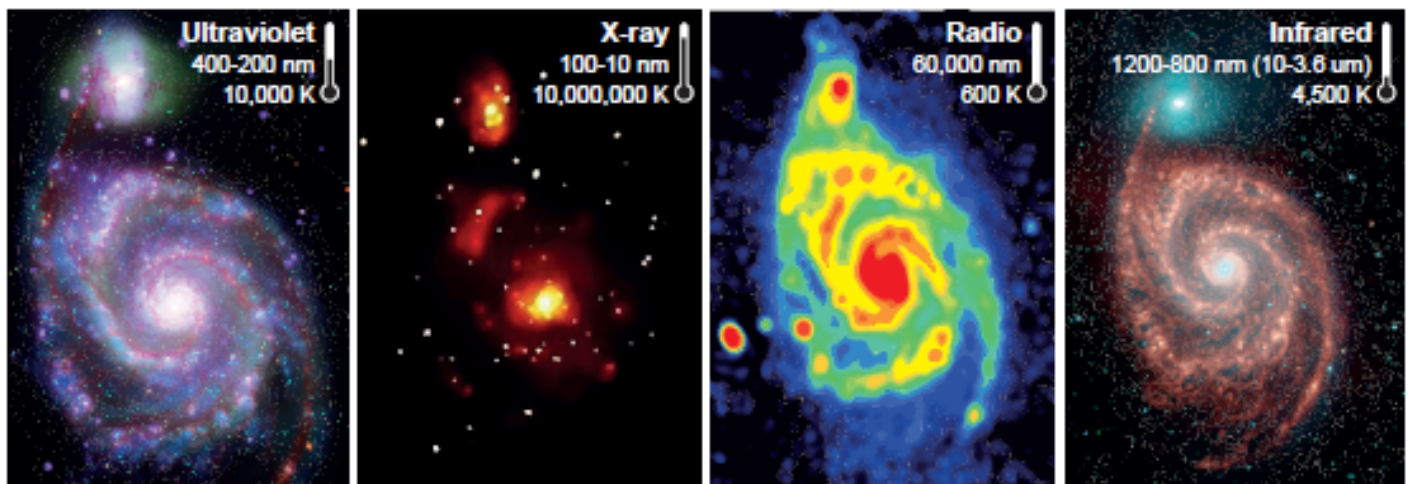
.....

.....

- (c) The image below is of the whirlpool galaxy, M51 (or NGC 5194). This is one of the first galaxies to be photographed by astronomers.



Subsequent images of the same galaxy are shown below.



Describe how these developments in observational astronomy have advanced the study of the whirlpool galaxy. [3]

.....

.....

.....

.....

.....

.....

8.

8. (a) Diagram 1 shows how the intensity of electromagnetic radiation from the Sun varies with distance from its centre. Diagram 2 shows how the intensity of the radiation incident on the Earth from the Sun is distributed across the spectrum.

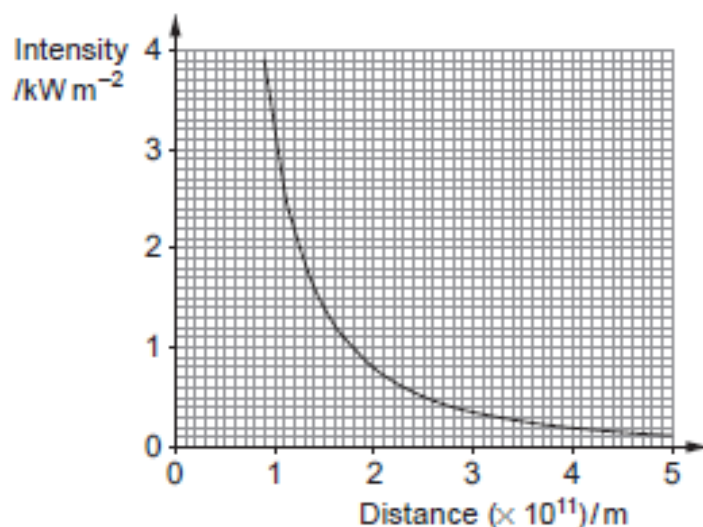


Diagram 1

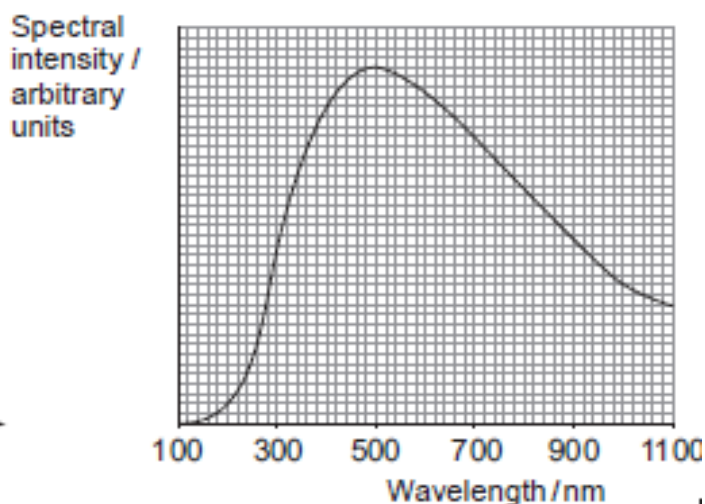


Diagram 2

- (i) Confirm that Diagram 1 shows the expected relationship between intensity and distance. [3]

.....

.....

.....

.....

.....

- (ii) Use Diagram 1 to show that the Sun's luminosity is about 4×10^{26} W. [2]

.....

.....

.....

- (b) In 2006 scientists from the University of Hawaii used a solar telescope aboard NASA's Solar and Heliospheric Observatory satellite to measure the radius of the Sun with (they quote) "unprecedented accuracy". They measured it to be:

$$R_{\text{sun}} = 696\,342 \text{ km}$$

Use information from Diagram 2 along with your answer to (a)(ii) to evaluate whether the information from Diagrams 1 and 2 are consistent with the scientists' findings. [5]

.....

.....

.....

.....

.....

.....

.....

.....

- (c) For centuries scientists have attempted to measure the Sun's diameter accurately. The following article is taken from a scientific paper written in 2004:

The solar diameter, and its possible variation, have been the subject of careful measurements for over 350 years, with ever increasing accuracy. Different techniques have been used, and the instrumentation has evolved in time. However, the long-term evolution of the Sun is still a controversial subject. Even for the short term, the results are inconsistent even with the most advanced instruments presently in use. These discrepancies probably have several origins.

[Past, present and future measurements of the solar diameter: Gerard Thuillier, Sabatino Sofia, Margit Haberleiter November 2004]

Suggest two reasons why it has been difficult for scientists to determine an accurate value for the Sun's diameter. [2]

.....

.....

.....

.....

Neutron stars are very small, dense ‘dead’ stars. Sometimes they can acquire an outer layer of ‘active’ material which becomes very hot and radiates as a *black body*. One such star has a **radius** of 11 km, and radiates at a temperature of 2.5×10^7 K.

- (a) (i) Show that the wavelength of greatest spectral intensity is approximately 1×10^{-10} m. [2]

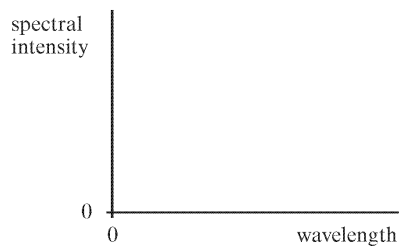
.....

.....

.....

- (ii) Name the region of the electromagnetic spectrum in which this wavelength lies. [1]

- (iii) Sketch a black body spectrum on the axes provided. [1]



- (iv) Discuss briefly whether the star in question emits any **visible** radiation. [1]

.....

.....

.....

- (b) Calculate the total *power* emitted as electromagnetic radiation by the star. [3]

.....

.....

.....

- (c) The outer layer of the star expands rapidly and cools. The total power emitted remains roughly constant. Estimate the temperature of the outer layer when its **surface area** has doubled. [2]

.....

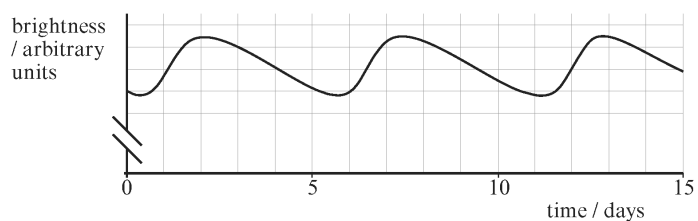
.....

.....

.....

10.

Cepheid variables are stars whose brightness varies in a characteristic, regular way. The variation is shown below for one such star.



The mean power, P , emitted as electromagnetic radiation from a Cepheid variable is related to the period of its brightness variation, as shown alongside.

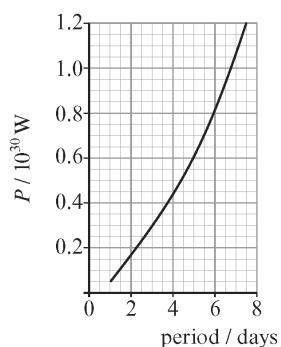
- (a) (i) Use the graphs to determine P for the star, showing briefly how you obtained your answer.

.....

.....

.....

.....



[2]

- (ii) The mean *intensity* of the radiation from the star, as measured at the Earth is $8.0 \times 10^{-13} \text{ W m}^{-2}$. Using your answer to (a)(i), calculate the distance, r , between the star and the Earth. [2]

.....

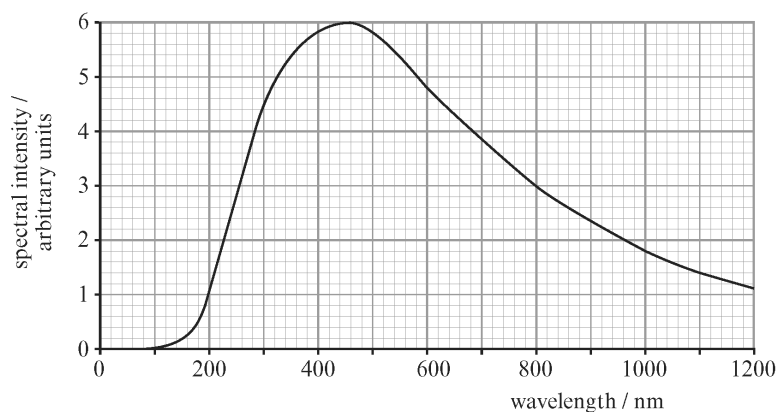
.....

.....

.....

.....

- (b) The maximum power emitted by the star during its cycle of variation is estimated to be $9.5 \times 10^{29} \text{ W}$, and the spectrum of its radiation corresponding to this point in its cycle is given below.



- (i) Use Wien's law to calculate the temperature of the star. [2]

.....

.....

.....

- (ii) Calculate the **diameter** of the star. [4]

.....

.....

.....

.....

.....

- (a) (i) The spectrum of the star *Rigel* in the constellation *Orion* peaks at a wavelength of 260 nm. Calculate the temperature of the surface of Rigel. [2]

.....

.....

.....

.....

- (ii) What assumption were you making about the way the star's surface radiates? [1]

.....

- (b) To a good approximation the Kelvin temperature of Rigel's surface is twice that of the Sun, and the **radius** of Rigel is 70 times the radius of the Sun. Use *Stefan's Law* to estimate the ratio

$$\frac{\text{total power of electromagnetic radiation emitted by Rigel}}{\text{total power of electromagnetic radiation emitted by the Sun}} . \quad [3]$$

.....

.....

.....

.....

.....

.....

.....

- (c) We can discover the presence of particular atoms in the atmosphere of a star by measuring the wavelengths of dark lines in the star's spectrum.

Explain how the lines arise, and why they occur at specific wavelengths. [3]

.....

.....

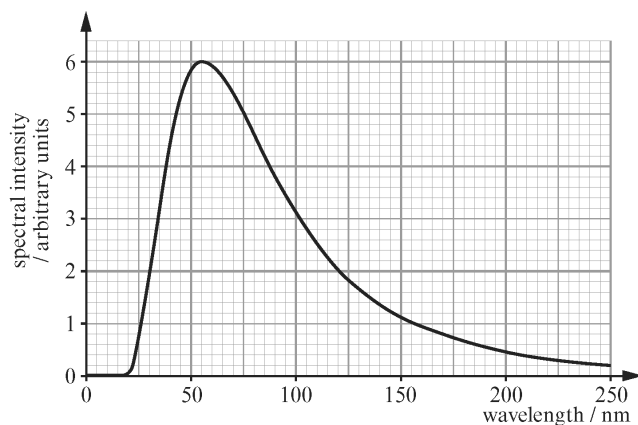
.....

.....

.....

12.

One of the hottest stars known is HD93129A in the Carina nebula. Its continuous spectrum is shown.



- (a) (i) Name the region of the electromagnetic spectrum in which the wavelength of peak emission lies. [1]

- (ii) Show that the star's temperature is approximately 50 000 K. [2]

.....

.....

.....

.....

- (iii) The star is blue. Explain how this could be deduced from the spectrum. [1]

.....

.....

- (b) (i) The star is 7.10×10^{19} m away, and the intensity of its electromagnetic radiation reaching the Earth is $3.33 \times 10^{-8} \text{ W m}^{-2}$. Show that its luminosity is approximately $5 \times 10^6 P_{\text{sun}}$, in which P_{sun} is the Sun's luminosity ($3.84 \times 10^{26} \text{ W}$). [3]

.....

.....

.....

.....

- (ii) Use Stefan's law to calculate the star's **diameter**. [3]

.....

.....

.....

.....

.....

7. The star Sirius A has a surface temperature of 9900 K and a luminosity (total power output of electromagnetic radiation) of 1.00×10^{28} W.

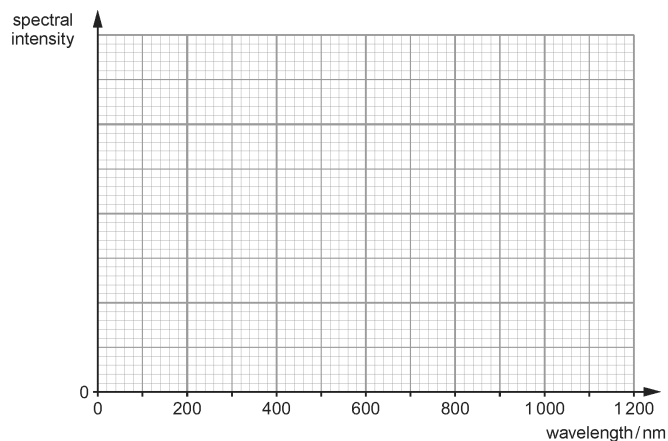
(a) (i) Calculate the star's wavelength of peak spectral intensity. [2]

.....

.....

.....

(ii) Sketch on the axes a graph of spectral intensity against wavelength for the continuous spectrum of Sirius A. (Note: make the peak spectral intensity three or four large squares above the wavelength axis.) [2]



(iii) What colour would you expect Sirius A to be? [1]

.....

(b) Use Stefan's Law to calculate the diameter of Sirius A. [3]

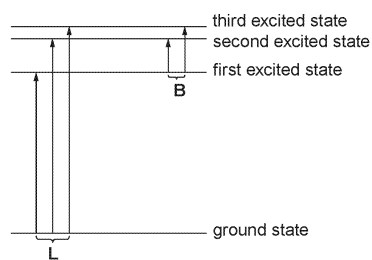
.....

.....

.....

.....

- (c) The diagram shows the lowest energy levels of a hydrogen atom, and five possible transitions between these levels.



- (i) Name the process (involving photons) which is responsible for the transitions. [1]

- (ii) Briefly describe the observed feature of the spectrum of a star which this process explains. [1]

- (iii) All the transitions shown in the diagram take place in the atmosphere of Sirius A. State which group of transitions, **L** or **B**, is almost completely absent in a much cooler star, giving a reason for your answer. [2]

A website gives the following data for the star Aldebaran:

$$\text{radius} = 44.2 R_{\odot} \quad \text{luminosity} = 518 L_{\odot}$$

in which $R_{\odot}$ = radius of Sun = $6.96 \times 10^8 \text{ m}$

and $L_{\odot}$ = luminosity of Sun = $3.85 \times 10^{26} \text{ W}$

- (a) Use Stefan's law to calculate a value for the surface temperature of Aldebaran. [4]

.....

.....

.....

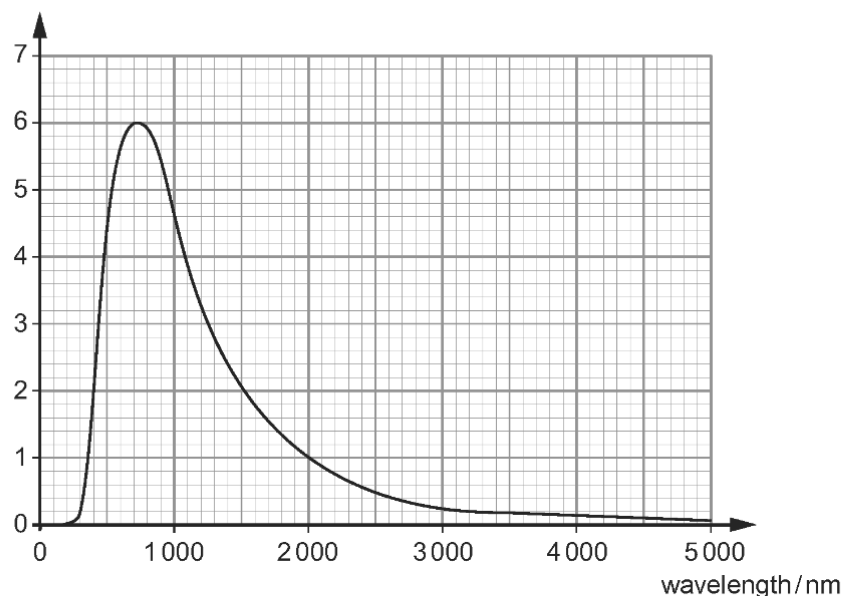
.....

.....

.....

- (b) The continuous spectrum of Aldebaran is given.

spectral intensity / arbitrary units



Determine a value for the temperature of Aldebaran without using Stefan's law giving your working. [2]

.....

.....

.....

- (c) Agreement between the temperatures found in (a) and (b) would help to confirm that Aldebaran is emitting as a black body. What is a black body? [1]

.....

.....

.....

- (d) Explain, using the data in this question, why 'red giant' is an appropriate description of Aldebaran. [2]

.....

.....

.....

.....

15.

(a) A table of astronomical data includes the following about the star *Alpha Centauri A*: Radius = 8.54×10^8 m, Temperature = 5790 K, Luminosity = 5.83×10^{26} W.

(i) Investigate whether the data above is consistent with the star radiating as a black body. Show your working clearly, and give your conclusion. [3]

.....

.....

.....

.....

.....

(ii) The star is 4.1×10^{16} m from the Earth. Calculate the intensity (energy per second per m^2) of electromagnetic radiation reaching the Earth from the star. [2]

.....

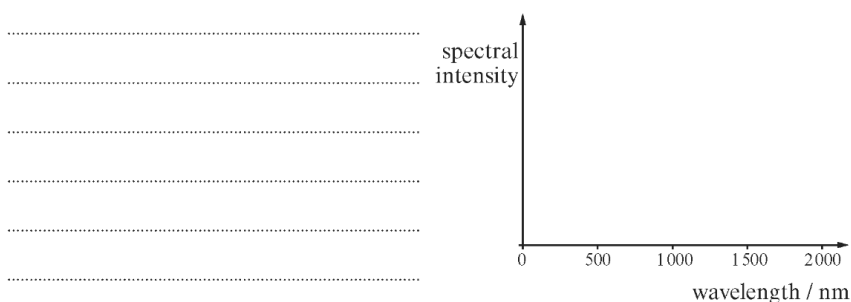
.....

.....

.....

.....

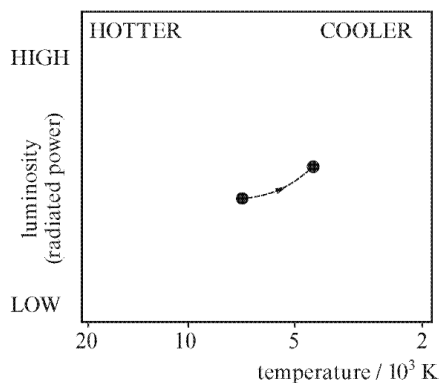
(iii) Calculate the wavelength of the star's peak spectral intensity, and sketch the spectrum on the axes provided. [4]



(b) Astronomers assign to each star a position on a chart, according to the star's luminosity and temperature.

During one stage in the life of *Alpha Centauri A*, its position on the chart will move as shown by the dotted line.

Use Stefan's law to show clearly what happens to the *size* of the star during this stage. [Numerical calculations are not needed.] [2]



.....

.....

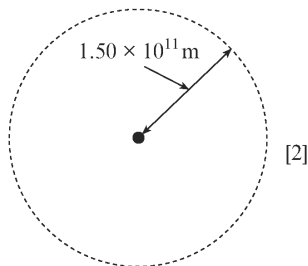
.....

.....

16.

- (a) (i) The *intensity* of the Sun's electromagnetic radiation at a distance of 1.50×10^{11} m from its centre is 1.36 kW m^{-2} .

Show that the power the Sun emits is approximately 4×10^{26} W. Give your answer to 3 significant figures.



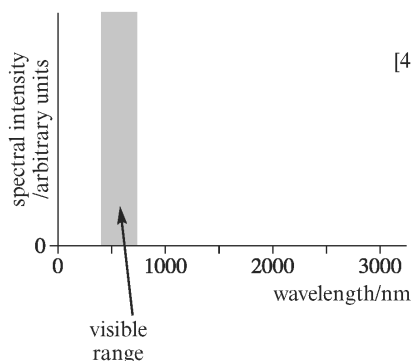
- (ii) 1.50×10^{11} m is the radius of the Earth's orbit. Suggest why the intensity of radiation, as measured on the Earth's surface, is less than 1.36 kW m^{-2} . [1]

- (b) The temperature of the Sun's surface is 5780 K.

- (i) Use Stefan's Law to calculate the *surface area* of the Sun. [2]

- (ii) The Sun's *diameter* is measured, by optical methods, to be 1.4×10^9 m. Show clearly whether or not your answer to (b)(i) is consistent with this. [2]

- (c) A biologist claims that our eyes are sensitive to the region of the Sun's spectrum of greatest intensity. Use Wien's law to support this claim, and sketch the Sun's spectrum on the axes provided.



1.	(a)	(i)	$T = \frac{W}{260 \times 10^{-9}} (1 - \text{trans}) \text{ [or by impl.]} [\text{allow this mark even if } 10^{-9} \text{ omitted}]$ $= 11 \times 10^3 \text{ K (1) ((unit))}$	2
		(ii)	Black body [accept: non-reflecting surface / radiates <u>equally</u> in all directions]	1
	(b)		Radius is $\times 70$ so area is $\times 70^2$ [or equiv, or by impl.] (1) Temperature is $\times 2$, so T^4 is 2^4 [or equiv. or by impl.] (1) [So] Power is $\times 80\,000$ (1)	3
	(c)		Absorption [by atoms in the stellar atmosphere or in interstellar gas] of specific wavelengths from the star's continuous spectrum [or from star's radiation / star's light] (1) Any 2 $\times$ (1) from: because photons of specific <u>energy</u> absorbed ✓ - Photon energies correspond to transitions between [atoms'] energy levels ✓ - Absorbed radiation re-emitted but in all directions ✓	3

Question			Marking details	Marks available				Maths	Prac
				AO1	AO2	AO3	Total		
4	(a)		Rearrangement $\sigma = \frac{P}{AT^4}$ and convincing algebra / cancellation of m^2 (1) P has units $\text{kg m}^2 \text{s}^{-3}$ (1) A has units m^2 and T^4 units K^4 (1)	1 1	1		3	1	
	(b)	(i)	$\lambda_p = 930 \pm 20 \text{ nm}$ (with units) (1) $T = \frac{2.9 \times 10^{-3}}{930 \times 10^{-9}} = 3\,120 \text{ K}$ (1) $A = 1.1 \times 10^{17} \text{ m}^2$ (1) $d = 1.87 \times 10^8 \text{ m}$ (1)	1	1 1 1		4	3	
		(ii)	Appears red and infra-red section			1	1		
			Question 4 total	3	4	1	8	4	0

3.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
8	(a)		Nebula, protostar, mid star, red giant, planetary nebula, white dwarf, black dwarf		1		1		
	(b)		Radiation/light not absorbed by atmosphere			1	1		
	(c)		Any one of these 4 marked [with a cross]. If more than one marked then follow the rule 1 right + 1 wrong = zero 		1		1		
	(d)		Photons collide with matter in star (or equivalent) [1] Force is rate of change of momentum [1] Light has momentum (or $p = \frac{h}{\lambda}$) [1]	1 1	1		3		
	(e)		More massive linked to greater gravitational force [hence density greater] [1] Greater density linked to increased [rate of] fusion [1] Reference to energy released <u>by fusion</u> e.g. more energy released [1]		3		3		
	(f)	(i)	$\lambda = \frac{0.0029}{T}$ used [1] Answer = 145 nm or $\frac{0.0029}{20\,000}$ seen (accept 17 000 K to 22 000 K from the graph) [1]	1	1		2	1	
		(ii)	Better to use UV or more radiation in UV or peak emission is not in visible range [1] [But] hot stars also emit visible light [more than colder stars] [1]			2	2		
	(g)		Choice of equation 1 e.g. $0.23 \times 0.2^{2.3}$ (=0.0057) [1] In (approximately) correct place (don't allow as a guess) [1]			2	2	2	
	(h)		Correct use of equation 3 e.g. $1.5 \times 10^{3.5}$ or 4 743 [1] Stated that luminosity or power or rate of use of fuel is 5 000× or 4 743× greater [1] Relevance of factor of 10 understood [1] Factor of 10 $M_{\odot}$ and 5 000 $L_{\odot}$ combined for a conclusion [1] e.g. $\frac{10}{5\,000}$ seen or $\frac{10}{4\,743}$ or worded answer e.g. although burning 5 000× faster, it has 10× more fuel so 500× less lifetime		4		4	2	
	(i)		As mass increases radius decreases or vice versa	1			1		
Question 8 total				4	11	5	20	5	0

4.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
4	(a)		An object that absorbs all electromagnetic radiation [incident upon it]	1			1		
	(b)		Conversion of temperature 310 K (1) Use of $P = \sigma A T^4$ (1) $P = 1047$ [W] No he is incorrect / conclusion (1)			3	3	2	
	(c)	(i)	Reasonable attempt at two black body graphs skewed normal distribution curves (1) Curve labelled blue all above curve labelled red (1) $\lambda_{\max}$ blue to the left of $\lambda_{\max}$ red (1)	1	1 1		3		
		(ii)	For distribution to have a peak wavelength of green other colours are emitted / green is in the middle of the (light) spectrum (1) Star will appear white (1)			2	2		
			Question 4 total	2	2	5	9	2	0

5.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
6	(a)		Indicative content: 1. Wavelength at peak intensity and Wien's Law [can be used to] determine [surface] temperature of the star. 2. Power emitted per square meter or area can be calculated using Stefan's law [details not required] 3. Colour of star can be deduced from wavelength of max intensity / spectrum. 4. Line absorption spectrum shown. 5. Line spectrum arises from passage of [continuous] spectrum/light/radiation / photons through stellar atmosphere 6. absorbing atoms/elements can be identified from wavelength of lines Other relevant points: - Total area under graph represents total power radiated - Absorption spectrum indicates temperature and generation of star - Redshift gives radial / recessional/ velocity/ distance - Reference to inverse square law and distance	6			6		
			5-6 marks At least 5 relevant points given <i>There is a sustained line of reasoning which is coherent, relevant, substantiated and logically structured.</i> 3-4 marks At least 3 relevant points given <i>There is a line of reasoning which is partially coherent, largely relevant, supported by some evidence and with some structure.</i> 1-2 marks At least 1 relevant points given <i>There is a basic line of reasoning which is not coherent, largely irrelevant, supported by limited evidence and with very little structure.</i> 0 marks <i>No attempt made or no response worthy of credit.</i>						
	(b)	(i)	Recall of $I = P \div 4\pi R^2$ in any form (1) Substitution: P (or Luminosity) = $1.32 \times 10^{-9} \times 4\pi \times (1.58 \times 10^{17})^2$ (1) $P = 4.1(4) \times 10^{27}$ W seen (1)	1	1 1		3	3	
		(ii)	Substitution: $P = A\sigma T^4$ in any form e.g.: $4 \times 10^{27} = A \times 5.67 \times 10^{-8} \times (7700)^4$ (1) [Accept $4.1(4)10^{27}$ for P] $A = 2.0 \times 10^{15} \text{ m}^2$ (1) [2.1×10^{15} if 4.14×10^{27} used] Diameter = $2.5 \times 10^9 \text{ m}$ (1) [2.6×10^9 if 2.1×10^{15} used] Use of πR^2 rather than $4\pi R^2 \rightarrow 5 \times 10^9 \text{ m}$ (2 marks)	1 1	1		3	3	
			Question 6 total	9	3	0	12	6	0

6.

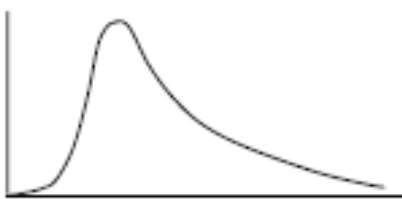
Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
6	(a)		5.1 [eV]	1			1		
	(b)		Particular wavelengths of the light are absorbed (1) Atoms or electrons are raised to higher energy levels (1) Light re-radiated in all directions (1)	3			3		
	(c)	(i)	Energy ($= \frac{hc}{\lambda}$) = 3.4×10^{-19} [J] (1) Conversion to eV = 2.1 [eV] (1) Correct conclusion with justification – does correspond to energy difference in levels (1)			3	3	2	
		(ii)	Wien's Law $\lambda_{\text{max}} = \frac{W}{T}$ (1) $T = \frac{2.9 \times 10^{-3}}{\lambda_{\text{max}}}$ (1) Temperature = 29 000 [K] (1)	1	1 1		3	3	
			Question 6 total	5	2	3	10	5	0

7.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
7	(a)		Continuous spectrum due to radiation of all wavelengths emitted from surface of star [1] [superimposed] line absorption spectrum (due to passage of radiation) through atmosphere (of star) [1]	2			2		
	(b)	(i)	Use of $I = \frac{P}{4\pi R^2}$ [1] Substitution: $\frac{I_s}{I_v} = \frac{9.7 \times 10^{27} \times [4\pi] (2.4 \times 10^{17})^2}{1.5 \times 10^{28} \times [4\pi] (8.1 \times 10^{16})^2}$ [1] Alternative for 2nd mark: Calculation of either intensity: $I_{\text{Sirius}} = 1.18 \times 10^{-7} \text{ [W m}^{-2}\text{]} \text{ or } I_{\text{Vega}} = 2.07 \times 10^{-8} \text{ [W m}^{-2}\text{]}$ Ratio = 5.7 [1]	1					
		(ii)	Shape of curve below that of Sirius at all points [1] Peak at $(1, \lambda_{\text{max}})$ ecf [1]		2		2		
		(iii)	Substitution into $P = 4\pi R^2 \sigma T^4$ i.e. $9.7 \times 10^{27} = 1.8 \times 10^{19} \times 5.67 \times 10^{-8} \times T^4$ [1] $T = 9.9 \times 10^3 \text{ K (9874 K) [1]}$ Substitution into $\lambda_{\text{max}} = \frac{W}{T} = \frac{2.90 \times 10^{-3} \text{ [m K]}}{9.9 \times 10^3 \text{ [K]}}$ ecf [1] $\lambda_{\text{max}} = 2.9 \times 10^{-7} \text{ [m] [1]}$	1 1	1 1		4	4	
	(c)		Reference to multiwavelength astronomy / using different parts of the em spectrum [1] Early photographs used visible light so limited / extra wavelengths provide extra information [1] Extra detail provided e.g. link between wavelength and temperature such as quasars at gamma / X-rays [1] This detail could be evidence for the 2 nd mark.			3	3		
			Question 7 total	5	6	3	14	6	0

8.

Question			Marking details	Marks available				Maths	Prac
				AO1	AO2	AO3	Total		
8	(a)	(i)	Reference to expected relationship: i.e. $I \propto \frac{1}{R^2}$ (1) Valid strategy e.g. $IR^2 = \text{constant}$ (1) [Award 2 marks for this] Data from graph used appropriately to confirm relationship: e.g. $(2 \times 10^{11})^2 \times 0.8 = 3.2 \times 10^{22}$ $(4 \times 10^{11})^2 \times 0.2 = 3.2 \times 10^{22}$ (1)			3	3	2	
		(ii)	Correct substitution of corresponding pairs of values into $I = \frac{P}{4\pi R^2}$ regardless of units used (1) Correct re-arrangement and correct unit conversions to show clearly that $P \approx 4 \times 10^{26}$ W e.g. $P = 1.4 \times 10^3 \times 4\pi \times (1.5 \times 10^{11})^2$ (1)	1	1		2	1	
	(b)		Either: λ_{peak} found from graph ($= 500 \times 10^{-9}$) (1) Wien's law to find T_{sun} i.e. $\frac{2.9 \times 10^{-3}}{500 \times 10^{-9}}$ ($= 5800$ K) (1) [(ecf on λ_{peak}]. Substitution into $P = 4\pi R_{\text{sun}}^2 \sigma T^4$ (ecf on T) e.g. $4 \times 10^{26} = 4 \times \pi \times R_{\text{sun}}^2 \times 5.67 \times 10^{-8} \times (5800)^4$ (1) [Allow A instead of $4 \times \pi \times R_{\text{sun}}^2$ but not $\pi \times R_{\text{sun}}^2$] or $A = 6.2 \times 10^{18} \text{ m}^2$. $R_{\text{sun}} = 7.0 \times 10^8 \text{ m}$ (1) Or: Luminosity from (a)(ii) (ecf) and radius substituted into $P = 4\pi R_{\text{sun}}^2 \sigma T^4$ (1) T calculated [expect 5830 K] (1) λ_{peak} calculated from Wien's law [5830 K $\rightarrow$ 497 nm] (1) λ_{peak} found from graph ($= 500 \text{ nm}$) (1) Appropriate comparison and comment: e.g. Either 700 000 km close to 696 342 km so reasonable comment. Or 700 000 km is '1000s' of km different, so unreasonable. Or λ_{peak} calculated in good agreement with graph (1)			5	5	4	
	(c)		Any 2 $\times$ (1) from: - Inaccurate instruments - Atmospheric distortions (e.g. refraction) - Earth/sun distance uncertainty - Uncertainty regarding solar surface- defining edge of sun - Sun varies in size over time. - Shape of disc is non-spherical - Brightness of disc overwhelms eye / instruments			2	2		
			Question 8 total	1	1	10	12	7	0

9.	(a)	(i)	$\lambda_{\text{peak}} = \frac{2.90 \times 10^{-3} \text{ K m}}{2.5 \times 10^7 \text{ K}} (1) = 1.16 \times 10^{-10} \text{ [m]} (1)$	2
		(ii)	X-ray / γ -ray	1
		(iii)		1
		(iv)	Spectral intensity low <u>in high λ 'tail'</u> but not zero.	1
	(b)		$P = \sigma A \times (2.5 \times 10^7 \text{ K})^4$ [or by impl.] (1) $A = 4\pi \times 11000^2$ [or by impl.] (1) [= $1.52 \times 10^9 \text{ m}^2$] $P = 3.4 \times 10^{31} \text{ W}$ (1) UNIT mark	3
	(c)		$A_2 T_2^4 = A_1 T_1^4$ (1) or $T_2^4 = \frac{3.4 \times 10^{31}}{5.67 \times 10^{-8} \times 3.04 \times 10^9} \text{ K}^4$ e.c.f from (b) $T_2 = 2.1 \times 10^7 \text{ K}$ (1)	2
10.	(a)	(i)	$= 5.4 [\pm 0.2] \text{ [day]} (1)$ $P = 0.70 [\pm 0.1] \times 10^{30} \text{ [W]} (1)$ ecf	2
		(ii)	$I = \frac{P}{4\pi r^2} (1)$ [or equivalent, or by implication] $r = 2.6 \times 10^{20} \text{ [m]} (1)$ ecf [1 mark only lost if factor of 4 omitted]	2
	(b)	(i)	$\lambda_{\text{peak}} = 450 \text{ n[m]} (1)$ [$\pm 10 \text{ nm}$] $T = 6400 \text{ [K]} (1)$ [ecf on λ_{peak}]	2
		(ii)	$A = \frac{P}{\sigma T^4} (1)$ [transposition at any stage] $= 10 \times 10^{21} \text{ [m}^2\text{]} (1)$ [or by implication] ecf on T $r = \sqrt{\frac{A}{4\pi}} (1)$ [= $2.8 \times 10^{10} \text{ [m]}$] [or by implication] $d = 5.6 \times 10^{10} \text{ [m]} (1)$ ecf (missing factor of 4 loses 1 mark)	4

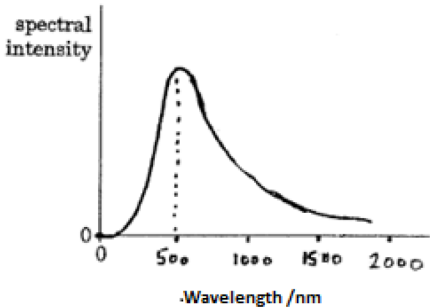
7	(a)	(i)	$T = \frac{W}{260 \times 10^{-9}} (1 - \text{trans}) \text{ [or by impl.]} \text{ [allow this mark even if } 10^{-9} \text{ omitted]}$ $= 11 \times 10^3 \text{ K (1) ((unit))}$	2
		(ii)	Black body [accept: non-reflecting surface / radiates <u>equally</u> in all directions]	1
	(b)		Radius is $\times 70$ so area is $\times 70^2$ [or equiv, or by impl.] (1) Temperature is $\times 2$, so T^4 is 2^4 [or equiv. or by impl.] (1) [So] Power is $\times 80\,000$ (1)	3
	(c)		Absorption [by atoms in the stellar atmosphere or in interstellar gas] of specific wavelengths from the star's continuous spectrum [or from star's radiation / star's light] (1) Any $2 \times (1)$ from: because photons of specific <u>energy</u> absorbed ✓ - Photon energies correspond to transitions between [atoms'] energy levels ✓ - Absorbed radiation re-emitted but in all directions ✓	3
				[9]

(a)	(i)	Ultraviolet [or u-v]	[1]
	(ii)	$\lambda_{\text{peak int}} = \underline{55 \text{ nm}}$ and $T = \frac{W}{\lambda_{\text{peak int}}}$ or by implication (1) $T = 53\,000 \text{ K}$ (1) ecf on 50 or 60 nm	[2]
	(iii)	In tail of curve [or equivalent] greater intensity at smaller λ . Accept blue end of visible nearer peak than red end.	[1]
(b)	(i)	$I = \frac{P}{4\pi r^2}$ (1) or equivalent so $P = 2.11 \times 10^{33} \text{ [W]}$ (1) or by implication So $P/P_{\text{sun}} = 5.49 \times 10^6$ or $5 \times 10^6 P_{\text{sun}} = 1.9 \times 10^{33} \text{ [W]}$ (1)	[3]
	(ii)	$A = \frac{P}{\sigma T^4}$ with A as subject ecf on P and T (1) or by implication $r = \sqrt{\frac{A}{4\pi}}$ (1) or $d = \sqrt{\frac{A}{\pi}}$ or by implication $d = 4.0 \times 10^{10} \text{ [m]}$ (1) [one mark lost for factor of 2 or 10^n adrift.]	[3]

13.	(a)	(i)	$\lambda_{\text{peak}} = \frac{2.90 \times 10^{-3}}{9900} \text{ [m] or equivalent (1)}$ $\lambda_{\text{peak}} = 293 \times 10^{-9} \text{ [m] (1)}$	2
		(ii)	Peak between 280 and 300 nm (1) Curve goes through origin [with zero gradient at origin] and is consistent with approaching zero at very long wavelengths (1)	2
		(iii)	Blue accept white or violet or purple	1
	(b)		$A = \frac{L}{\sigma T^4}$ with A as subject, with symbols or data or $1.84 \times 10^{19} \text{ m}^2$ (1) Attempt to use $A = 4\pi r^2$ and $d = 2r$ or $A = \pi I^2$ (1) $d = 2.4 \times 10^9 \text{ m}$ ecf on slips of 2^n or 10^n if already penalised (1)	3
	(c)	(i)	Absorption accept excitation Don't accept pumping	1
		(ii)	Dark / black lines crossing or missing wavelengths [continuous] spectrum or coloured background	1
		(iii)	B almost absent and any reference to populations of levels (1) First excited state not populated [so no transitions start here] or all electrons in ground state (1)	2

14.

Question			Marking details	Marks Available
7	(a)		$r = 3.07 \times 10^{10} \text{ m}$ and $L = 1.99 \times 10^{29} \text{ W}$ or by implication (1) $L = \sigma 4\pi r^2 T^4$ (1) Correct algebra including fourth-rooting (1) $T = 4150 \text{ K}$ UNIT mark (1) [Take 5865 K arising from $A = \pi r^2$ as ecf] If only Sun considered $T = 5776 \text{ K}$ award 3 marks only	4
	(b)		Attempted use of $\lambda_{\text{max}} = 700 - 750 \text{ [nm]}$ in Wien's Law (1) $3867 - 4140 \text{ [K]}$ (1)	2
	(c)		Black body absorbs all [electromagnetic] radiation (accept light) falling on it. [Accept: Black body emits more radiation per second [or equivalent] [at every wavelength] than any other body at same temperature. Don't accept it is a perfect emitter.	1
	(d)		Spectrum peaks in red or equivalent. Accept infra-red. (1) $r = 44.2 R_{\odot}$ is sufficient. Must compare with the Sun. (1)	2
			Question 7 Total	[9]

Question			Marking details	Marks Available
(a)	(i)		$A = 4\pi(8.54 \times 10^8 \text{ [m]})^2$ (1) $[9.16 \times 10^{18} \text{ [m}^2\text{]}]$ $P = 5.67 \times 10^{-8} \times \text{area attempt} \times 5790^4$ (1) [W] $P = 5.84 \times 10^{26} \text{ [W]}$ and consistency ecf on slips (1) [One mark to be lost for slips e.g. powers of 10, factors of 2, 4, π] Or alternative solution using Stefan's law is acceptable.	[3]
	(ii)		$I = \frac{\text{power}}{4\pi(4.1 \times 10^{16})^2}$ (1) $I = 2.76 \times 10^{-8} \text{ Wm}^{-2}$ UNIT (1) [penalty of 1 mark for slips of 10^n , 4, π etc no penalty if same slip as in (i)]	[2]
(b)	(iii)		$\lambda_{\text{pmax}} = \frac{2.9 \times 10^{-3}}{5790}$ (1) $= 5.01 \times 10^{-7} \text{ [m]}$ (1) GRAPH - Goes through origin and doesn't hit the axis (1) Peak at $\sim 500 \text{ nm}$ (Apply ecf) (1)	[4]
				
	(b)		P goes up and T goes down and then A goes up (1) Because $A = \frac{P}{\sigma T^4}$ or any convincing explanation (1)	[2]
Question 6 Total				[11]

16.	(a)	(i)	Power = intensity $\times 4\pi r^2$ (1) = $3.8[5] \times 10^{26}$ W (1) [1 mark lost for factors of 2, 3 or 10^n adrift]	2
		(ii)	absorption by atmosphere.	1
	(b)	(i)	$A = \frac{3.85 \times 10^{26}}{5.67 \times 10^{-8} \times 5780^4} \text{ m}^2$ [e.c.f.] (1) = $6.1 \times 10^{18} \text{ m}^2$ (1) [$6.08 \times 10^{18} \text{ m}^2$]	2
		(ii)	<i>Either</i> $d = 2\sqrt{\frac{A}{4\pi}}$ [or equiv.] (1) $= 1.39 \times 10^9 \text{ m}$ (1) <i>Or</i> $A = 4\pi \left[\frac{d}{2} \right]^2$ (1) $= 6.15 \times 10^{18} \text{ m}^2$ (1)	2
	(c)		$\lambda_{\text{max}} = \frac{W}{T} = \frac{2.90 \times 10^{-3} \text{ mK}}{5780 \text{ K}}$ (1) $= 500 \text{ nm}$ [which is in the visible] (1) Sketch graph of correct general shape (1) with peak at 500 nm [e.c.f.] (1)	4
				[11]

Examiner's Comments

1. (mean mark: 3.5/9 = 39 %)

- (a) (i) Most candidates used Wien's law correctly, to work out Rigel's surface temperature. Those who failed were often thrown by the way the formula is presented on the equation sheet - in terms of λ . The sheet is provided to confirm candidates' recall of formulae which they should already know how to use!

(ii) The assumption made was that the star radiates as a black body. Equal radiation in all directions wasn't given the mark as it's not relevant to the shape of the spectrum.

- (b) For those candidates with good algebraic competence the question could be answered neatly in this way:

$$P_{\text{Rigel}} = 4\pi(70r_{\text{Sun}})^2(2T_{\text{Sun}})^4 = 4\pi 70^2 r_{\text{Sun}}^2 2^4 T_{\text{Sun}}^4 = 70^2 \times 2^4 = 78000$$

$$P_{\text{Sun}} = 4\pi r_{\text{Sun}}^2 T_{\text{Sun}}^4$$

We did see this sometimes, but there were many more instances where something similar was attempted, but with at least one pair of brackets omitted - with bad consequences.

Less mathematically able candidates were probably better served by more numerical approaches. One mark was awarded immediately, for example, if we saw 110004/55004. It was perfectly acceptable to make up a figure for the Sun's radius so that the ratio of surfaces areas could be handled in the same way.

- (c) Explanations of why dark lines appear at specific wavelengths in a star's spectrum were in general disappointing. We wanted answers in terms of photons and energy levels in atoms, but many candidates who attempted this approach did not give coherent accounts.

This comment originally referred to question 7 on paper 1322/01 (06/06/2011)

2. There are no examiner comments available for this question

3. There are no examiner comments available for this question

4. There are no examiner comments available for this question

5. There are no examiner comments available for this question

6. There are no examiner comments available for this question

7. There are no examiner comments available for this question

8. There are no examiner comments available for this question

9. Mean mark: 6.6/10 = 66%

- (a) (i) Using Wien's law gave little trouble.

(ii) Gamma ray or X-ray was accepted as the region including a wavelength of 10^{-11} m. UV and IR were the commonest unacceptable answers.

(iii) A humped graph passing through the origin and not threatening to hit zero at high wavelengths was required. Note that the graph slope at the origin is zero; the graph climbs off the λ axis a little way from the origin.

(iv) A few candidates used the curious wrong reasoning that no visible light would be emitted because the peak wavelength was not in the visible, but many realised that the total power was so high that some visible would be emitted in the long λ 'tail'.

- (b) Stefan's law was used, with complete success by many, though the usual errors abounded. There were incorrect formulae used for the surface area of a sphere, and incorrect powers of 10. Sometimes the unit of power was wrong or omitted.

- (c) Estimating the surface temperature of the expanded star was the 'difficult' last part of the question but, surprisingly, correct answers were common - and often came from candidates who had met with little success earlier in the question.

This comment originally referred to question 6 on paper 1322/01 (20/01/2012)

10. (a) (i) Extracting the period (5.4 ± 0.2 days) from the Cepheid brightness graph and reading off the mean power from the second graph, was conceived as an easy 'process task'. Alas, it proved, a terrible stumbling block for almost everyone. The problem may have been caused by candidates not understanding what 'period of brightness variation' meant - especially for a non-sinusoidal graph. This is regretted. Quite often, though, the second of the two marks was given on the ecf principle, and it was very rare for candidates to have no answer at all to take to the next part of the question.

(ii) Finding the distance away from us of the star, given its radiation power, and the intensity of light that we receive from it, defeated many candidates - as it has done when asked in previous papers. No equation is given on the data sheet; candidates have to remember it or derive it - a one-liner. It was depressing to see a number of candidates attempting to put figures into Stefan's law, even though temperature did not feature in this part of the question.

- (b) (i) Most candidates found the star's temperature correctly using Wien's law, though a few did not know which wavelength to use, and/or made mistakes with the algebra. It is not guaranteed that outrageous answers (e.g. a stellar temperature of 3.8×10^{-38} K), if not remarked upon, will attract full ecf credit.

(ii) It was good to see many successes in working out the star's diameter, with fewer mistakes (such as failures to raise T to the fourth power, or wrong area formulae) than sometimes seen.

This comment originally referred to question 8 on paper 1322/01 (25/05/2012)

11. (a) (i) Most candidates used Wien's law correctly, to work out Rigel's surface temperature. Those who failed were often thrown by the way the formula is presented on the equation sheet - in terms of λ_{max} . The sheet is provided to confirm candidates' recall of formulae which they should already know how to use!

(ii) The assumption made was that the star radiates as a black body. Equal radiation in all directions wasn't given the mark as it's not relevant to the shape of the spectrum.

(b) For those candidates with good algebraic competence the question could be answered neatly in this way:

We did see this sometimes, but there were many more instances where something similar was attempted, but with at least one pair of brackets omitted - with bad consequences.

Less mathematically able candidates were probably better served by more numerical approaches. One mark was awarded immediately, for example, if we saw 110004/55004. It was perfectly acceptable to make up a figure for the Sun's radius so that the ratio of surfaces areas could be handled in the same way.

(c) Explanations of why dark lines appear at specific wavelengths in a star's spectrum were in general disappointing. We wanted answers in terms of photons and energy levels in atoms, but many candidates who attempted this approach did not give coherent accounts.

This comment originally referred to question 7 on paper 1322/01 (06/06/2011)

12. (a) (i) λ_{max} is 55 nm, which is indisputably in the ultraviolet region. This was the commonest answer, though visible was quite popular, and we saw more than one gamma.

(ii) As usual Wien's law was almost always selected and correctly applied.

(iii) To deduce that the star is blue, candidates needed to say that the intensity (from the trend of the graph) is going to be greater at 400 nm than 700 nm, or that the peak of the graph is closer to the blue (shorter wavelength) end of the visible region. The mark was often not given. The curious phrase "the star's wavelength" was sometimes seen.

(b) (i) There was rather more success than in the past in calculating the star's luminosity from its intensity, and the comparison with P_{sun} was generally convincing.

(ii) Many candidates (probably the majority if we include those who made slips of factors of 2 or 4) applied Stefan's law correctly to find the star's diameter. Quite often the wrong figure for the luminosity was imported from (b)(i), incurring a small penalty.

This comment originally referred to question 7 on paper 1322/01 (05/06/2013)

13. (a) (i) Mistakes in the Wien's law calculation were rare.

(ii) The spectral intensity against wavelength sketches could be rather sloppy, with positive (rather than zero) gradients at the origin, peaks noticeably out of place and/or high wavelength tails hitting the wavelength axis.

(iii) With the peak wavelength, one would expect the star to be bluish. We accepted blue, violet, white, but not yellow, orange or red. Most candidates (but not by a huge majority) were given the mark.

(b) The Stefan's law calculation was very well done, with, perhaps, fewer candidates than in the past using rather than, or forgetting to double the radius to get the diameter, though these faults were still seen.

(c) (i) The transition shown represented (photon) absorption. We also accepted excitation, but not pumping.

(ii) The question asked for the observed feature of the specimen to be described. We wanted "black lines on a bright background" or something similar. Very often we were given something much more abstract, and often, simply wrong.

(iii) This was conceived as a hard question, and indeed only a minority of candidates realised that populations were the key. In a cool star the first excited state is almost empty, so there are hardly any electrons in a fit state to undergo the 'B' transitions.

This comment originally referred to question 7 on paper 1322/01 (09/06/2014)

14. Q.7 (a) Most candidates knew how to re-arrange Stefan's law to obtain a star's temperature. The commonest mistake, which arose from poor reading of the question, and cost one mark, was to enter data for the Sun rather than for Aldebaran. As usual, some candidates took the area of a sphere as πr^2 ; again a single mark penalty. A few candidates did not seem to realise that *luminosity* meant *power*. If only they had looked at the units!

(b) Wien's law was usually used successfully. Examiners had to watch out for candidates obtaining roughly the right figure for temperature by multiplying together the co-ordinates of the peak, as read from the scales. This was seen several times.

(c) A black body is a surface that absorbs all electromagnetic radiation falling on it. That's it. Longer versions, such as "...absorbs all *wavelengths* of e-m radiation..." are not as good. A few candidates attempted to define a black body in terms of its radiation *emission*; this was just as well because the wording needs to be very careful.

(d) Why is *red giant* an appropriate description of Aldebaran? Some candidates tackled only *red* or *giant*. For the *red* part, we accepted the answer most frequently given, that the peak wavelength of 700 nm is at or near the red end of the visible spectrum. We did want the word *peak* or its equivalent. As for *giant*, all that was needed was to refer back to its radius being 44 times that of the Sun. Just to say it was large wasn't enough.

This comment originally referred to question 7 on paper 1322/01 (04/06/2015)

15. Mean mark: $6.3/11 = 57\%$

(a) (i) To show whether or not the star radiated as a black body, most candidates chose to calculate the power emitted using Stefan's law, and to compare it with the given luminosity. An elegant variation was to use the data given to check whether it gave the right value for the Stefan constant. The reasoning was usually clearly set out and the success rate was high. Common faults were to use $\frac{1}{2}\pi r^2$ for the surface area of a sphere, and to omit to draw a conclusion. If, in such a question, the expected result is not confirmed, this should be stated and discussed briefly in the conclusion; a slip (such as a missing factor of 4) will not then attract a double penalty.

(ii) Calculating the intensity on the Earth of the star's radiation elicited, as usual, many bizarre attempts. This may be because no formula is given on the sheet, though this shouldn't have come as a surprise! Common mistakes included evaluation of power/r^2 and of $\text{power}/4\pi r^2$, but with r equal to the star's radius.

(iii) The great majority could use Wien's law successfully to find the wavelength of peak emission. Many good spectra were drawn, but we saw several graphs with positive intercepts on the vertical axis, corresponding to finite spectral intensity at zero wavelength. *This is wrong*. The graph goes through the origin and its slope at the origin is zero; it parts company noticeably from the λ axis a little way from the origin.

(b) Most candidates gained a mark for noting that T decreased, power, P , increased, and so A increased. Fewer could justify their deduction about A ; it sufficed to make A the subject of the Stefan's law equation. A significant number of candidates took P as constant.

This comment originally referred to question 6 on paper 1322/01 (18/01/2013)

16. (mean mark: 6.7/11 = 42%)

- (a) (i) The mention of power output of a star meant only one thing to quite a significant minority of students: the Stefan-Boltzmann Law. Not having the star's temperature seemed to be no deterrent to putting some figures into the formula.
- (ii) The intensity of radiation measured on the Earth's surface is less than the intensity at 1.50×10^{11} m from the Sun (i.e. at the Earth's orbital radius). Many students attributed the discrepancy to absorption by interstellar dust or other material in 'space', rather than by the Earth's atmosphere. The question clearly needed thinking about a little more carefully!

This comment originally referred to question 8 on paper 1322/01 (17/01/2011)