1. (a) Give the equation which represents *Stefan's law* for a black body source of radiation, defining the symbols used.

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(3)

(b) (i) The space probe Voyager I is travelling out of the solar system and is, at present, approximately 8000×10^6 km from the Sun. The power source on board is a nuclear generator providing 400 W. If this power had to be obtained from solar panels, calculate the area of the solar panels which would be necessary.

power received on Earth from the Sun = 1400 Wm^{-2}
distance of the Earth from the Sun = 150×10^6 km

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(ii) State **one** assumption you have made in the calculation.

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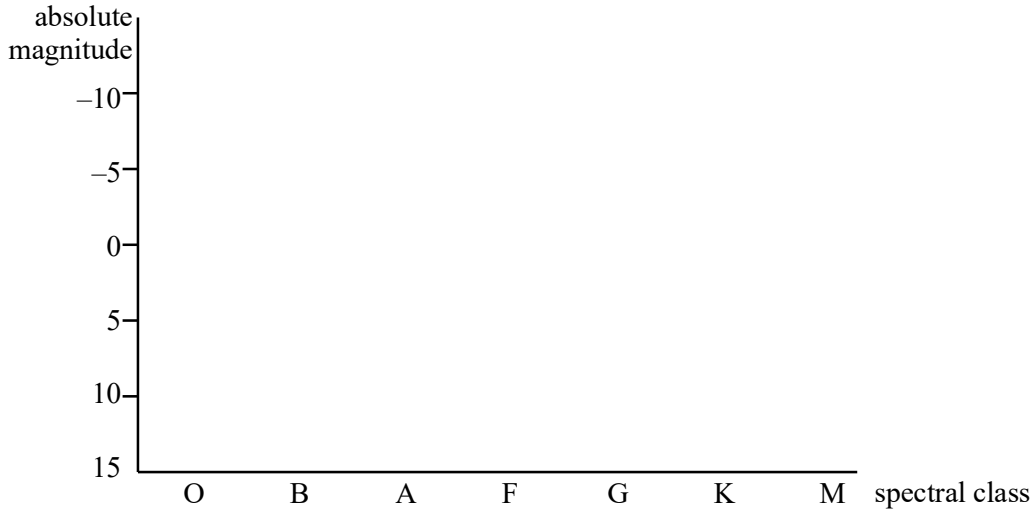
(5)
(Total 8 marks)

2. (a) Use the axes to draw a labelled Hertzspung-Russell diagram which shows the regions of the Main Sequence stars, White Dwarfs and Red Giants. Label the approximate position of the Sun.



(3)

(b) The table contains information about five different stars.

star	apparent magnitude	spectral type	parallax/ arc seconds
Aldebaran	0.85	K	0.054
Formalhaut	1.16	A	0.149
Hassaleh	3.19	F	0.137
Spica	0.98	B	0.023
tau Ceti	3.50	G	0.287

Using data from the table, state, with a reason,

(i) which star appears brightest in the sky to us,

.....

.....

(ii) which star appears reddest in the sky.

.....

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(4)

(c) (i) Tau Ceti is a Main Sequence star. Use the Hertzsprung-Russell diagram and data from the table to determine an approximate value for its absolute magnitude.

.....

(ii) Hence estimate the distance, in parsec, of tau Ceti from Earth.

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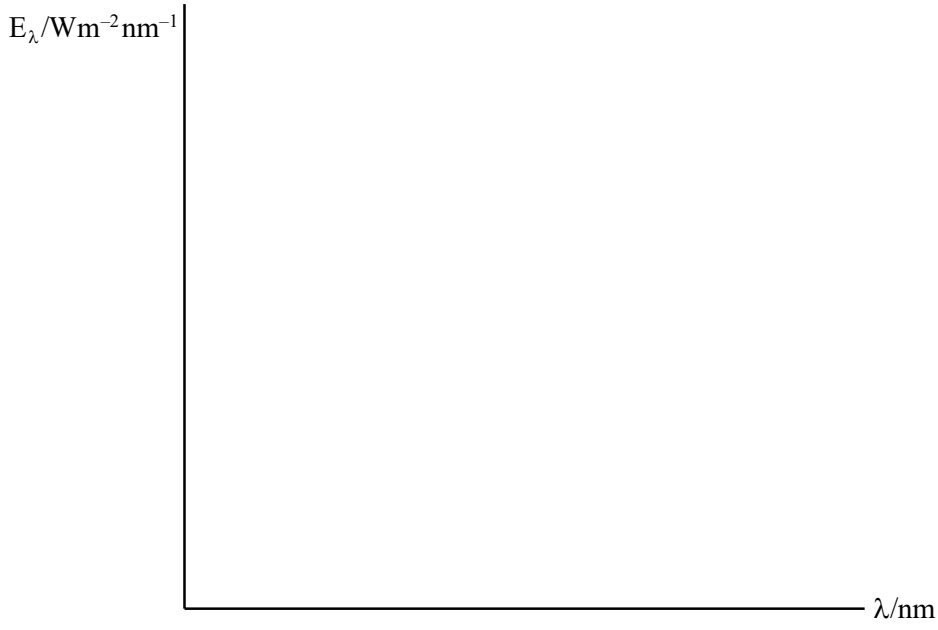
(3)

(Total 10 marks)

3. (a) Using the axes below, sketch the emissive power of a black body, E_λ, as a function of wavelength for each of three temperatures, 1000 K, 1200 K and 1600 K. Indicate the temperature on each curve.



(3)

(b) (i) *Wien's displacement law* may be written as $\lambda_{max}\ T$ = constant. State what λ_{max} represents.

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.....

(ii) Obtain the value of the constant from the Data Sheet and calculate λ_{max} for a temperature of 1600 K.

.....

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(iii) Assuming that λ_{max} for the Sun lies within the range of the visible spectrum, use Wien's law to estimate the temperature of the Sun.

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(5)

(c) Stefan's law for a black body may be written as $E = \sigma T^4$ where E, the energy radiated per second per square metre of the surface area, has units W m^{-2}.

(i) Hence state how a value of E may be obtained from one of the curves drawn in part (a) for a given temperature.

.....

.....

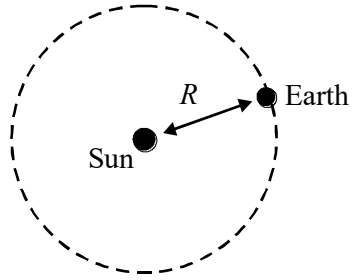
(ii) For a black body of surface area A, give Stefan's law in the form which gives total radiative power of the body.

.....

(2)

(d) (i) The diagram represents the Earth in orbit around the Sun. Given that the Earth receives 1400 W m^{-2} of energy from the Sun and that the Sun emits energy equally in all directions, estimate the total output power, in W, of the Sun.

mean radius, R, of the Earth's orbit around the Sun = 1.5×10^{11} m



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(ii) Hence, use Stefan's law to deduce the temperature of the Sun.

radius of the Sun = 7.0×10^{8} m

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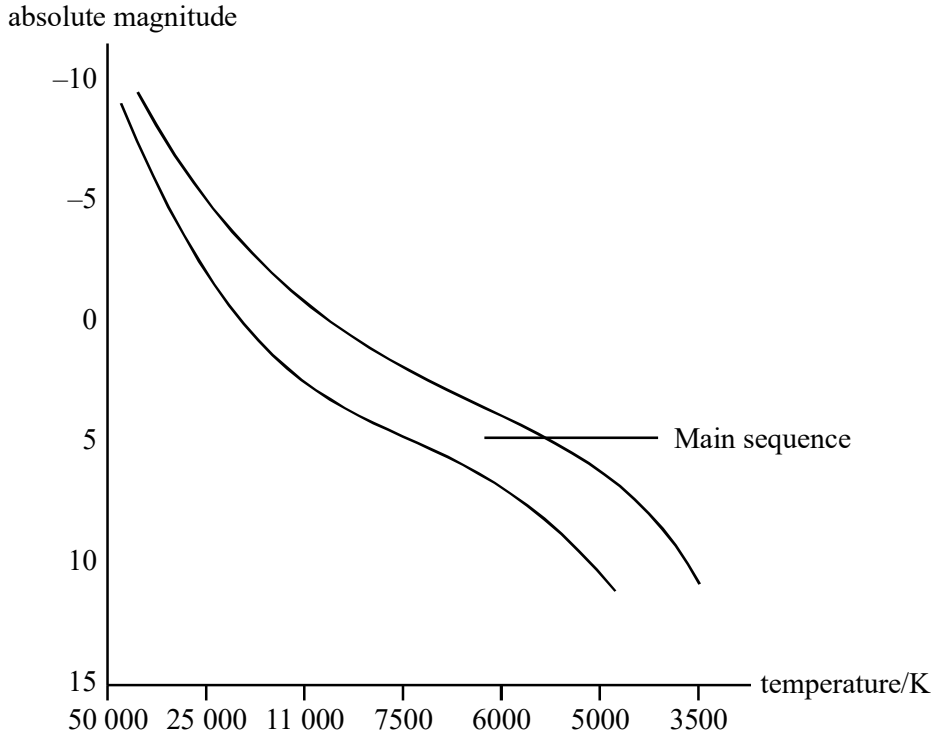
(4)
(Total 14 marks)

4. A Hertzsprung-Russell diagram for Main Sequence stars is shown below.



(a) (i) Label on the diagram the regions occupied by White Dwarfs and Red Giants.

(ii) Use the diagram to explain why Red Giant stars must be very much larger than White Dwarfs.

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(4)

(b) (i) Mark the spectral classes O to M on the diagram.

(ii) Describe briefly the spectra of stars in class O, class A and class M.

class O .....

.....

.....

class A .....

.....

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class M .....

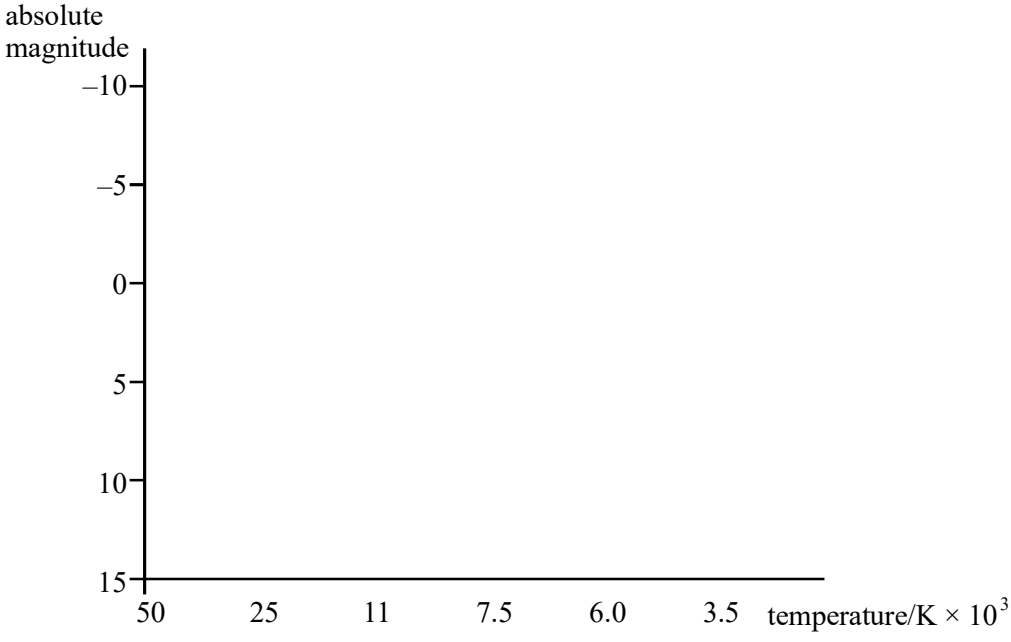
.....

.....

(6)

(Total 10 marks)

5. (a) Sketch a Hertzsprung-Russell diagram using the axes below. Label the approximate positions of main sequence stars, Red Giant stars, White Dwarf stars and the Sun.



(3)

(b) The evolution of a star from the main sequence depends on its mass. A certain star in the main sequence, in a position close to the Sun, evolves into a Red Giant.

(i) Compare the brightness of this star when it is a Red Giant to when it was in the main sequence.

.....

(ii) Given that the hydrogen in this star undergoes fusion, suggest a sequence of events which causes this star to evolve into a Red Giant.

.....

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(4)

(c) Nova Muscae is believed to be a black hole with a mass approximately three times that of the Sun.

(i) What property of this star causes it to be a black hole? Explain why it is so named.

.....

.....

(ii) State what is meant by the term *event horizon* and calculate the radius of the event horizon for this star, using data from the Data Sheet.

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.....

.....

(5)

(Total 12 marks)

6. The table gives information on two stars.

star	apparent magnitude	spectral class	distance/pc
Proxima Centauri	11	M	1.30
Antares	1.0	M	160

(a) (i) Explain what is meant by

apparent magnitude .....

.....

absolute magnitude .....

.....

(ii) The two stars named in the table are viewed through a telescope. State and explain **one** difference in the appearance of the two stars.

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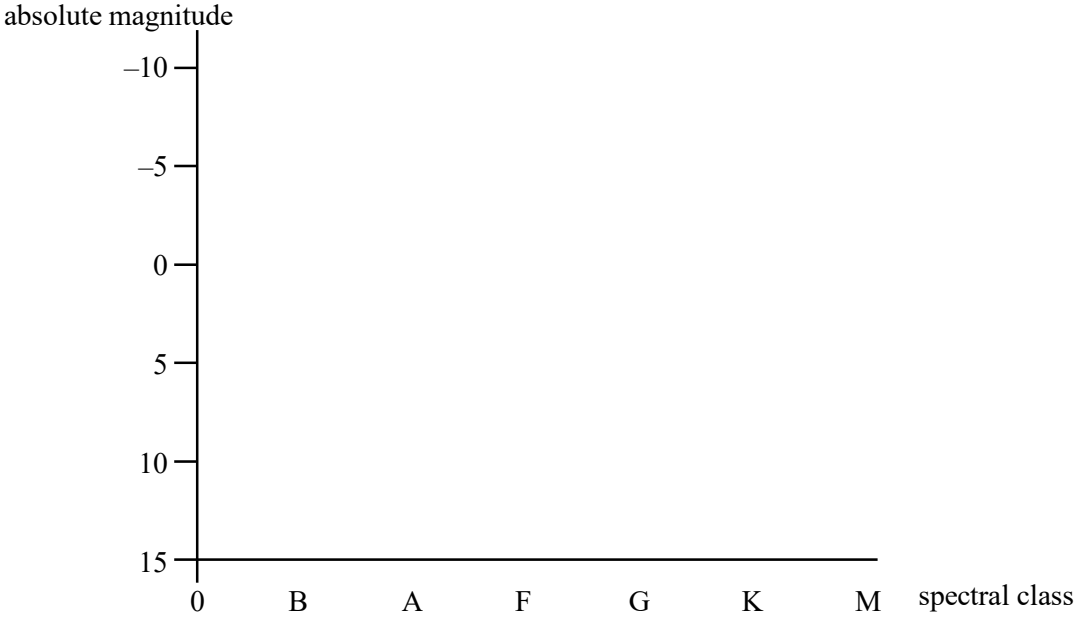
(4)

(b) (i) Draw a Hertzsprung-Russell diagram for main sequence stars, Giant Stars and White Dwarfs.



(ii) With reference to the table, calculate the absolute magnitude of Proxima Centauri.

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(iii) Given that the absolute magnitude of Antares is -5, mark and label with an X its approximate position on the Hertzsprung-Russell diagram.

(6)

(c) (i) Giving your reason, what can you say about the surface temperature of the two stars?

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.....

(ii) Hence, deduce which star has the larger diameter. Explain how you arrive at your answer.

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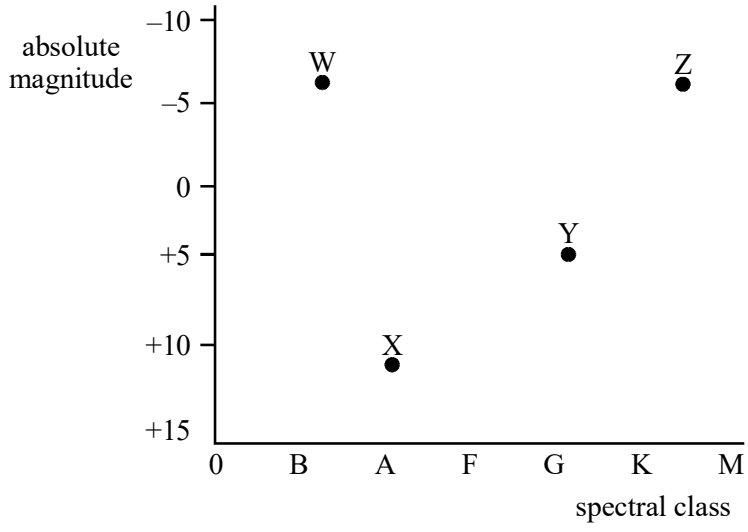
(4)

(Total 14 marks)

7. The absolute magnitude and spectral class of four stars W, X, Y and Z are plotted using the axes below.



(a) Draw and label, on the diagram above, the regions occupied by the main sequence, white dwarf stars and red giant stars.

(2)

(b) The following observations were made for the star Alnilam in the constellation of Orion.

apparent magnitude:	1.7
distance from Earth:	1350 light years
spectrum:	strong hydrogen Balmer absorption lines

(i) Explain what is meant by *apparent magnitude*.

.....

.....

(ii) Calculate the distance in parsecs of Alnilam from the Earth.

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(iii) Hence calculate the absolute magnitude of Alnilam.

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(iv) Which of the stars, W, X, Y or Z is Alnilam? Explain your answer.

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(7)

(c) The stars shown on the graph could represent the position of a star at different times during its evolution. Write down the correct sequence, using some or all of the letters, that would best represent the evolution of the Sun starting from its present position.

.....

(1)

(Total 10 marks)

8. The table compares two properties of the Sun with Arcturus, a star in the constellation Bootes.

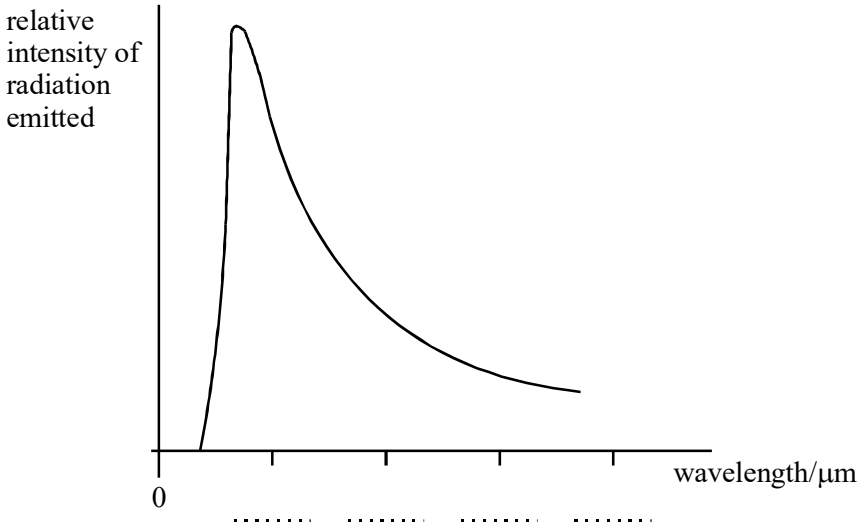
	Sun	Arcturus
surface temperature / K	6 000	5 000
absolute magnitude	5	0

(a) (i) Assuming the Sun acts as a black body, calculate the wavelength at which maximum emission occurs in its spectrum.

.....

.....

(ii) The graph shows the black body radiation curve for the Sun. Use your answer to (a) (i) to enter values on the wavelength axis in the 4 places provided.



(iii) Without calculation, sketch on the axes above a black body curve for Arcturus.

(4)

(b) (i) Explain how the information in the table indicates that Arcturus is 100 times brighter than the Sun.

.....

.....

(ii) Assuming that the power output of Arcturus is 100 times greater than that of the Sun, show that its surface area must be approximately 200 times greater.

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(4)
(Total 8 marks)

9. (a) In 1054 a *supernova* was observed in the constellation Taurus. The remnants can be seen as the Crab Nebula, which has a very faint neutron star at its centre.

(i) State what is meant by a superova.

.....

.....

(ii) State **two** properties of a typical neutron star.

.....

.....

.....

(3)

(b) Much evidence is being produced suggesting that galaxies have black holes at their centres. For example, the spiral galaxy M51 may contain a black hole with a mass one million times greater than the Sun.

(i) Explain what is meant by the term *event horizon.*

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(ii) Calculate the radius of the event horizon for the black hole in M51.

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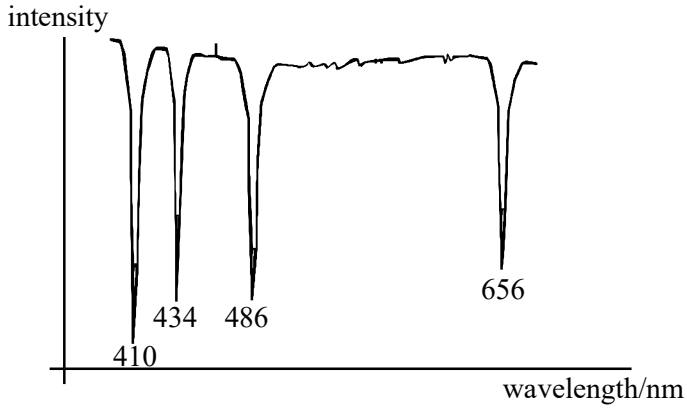
(4)
(Total 7 marks)

10. (a) The graph shows part of the visible region of the spectrum of the star Vega.



The absorption lines are due to excited hydrogen atoms. The wavelength of each absorption is given in nm.

You may be awarded marks for the quality of the written communication provided in your answer.

(i) Explain how hydrogen atoms produce these absorption lines.

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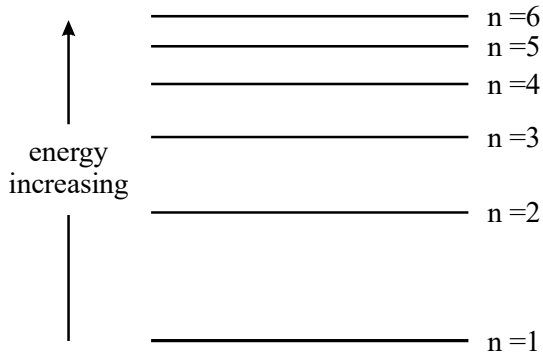
(ii) The diagram below shows the first six energy levels of a hydrogen atom. Draw an arrow to show the largest energy transition which produces an absorption line in the **visible** spectrum of Vega.



(iii) State the value of the wavelength corresponding to this transition.

.....

(iv) What is the name given to the series which gives rise to the visible region of the hydrogen spectrum?

.....

(v) For which spectral classes are these lines the dominant feature?

.....

(4)

(b) (i) The wavelength at maximum intensity in the spectrum of Vega has a value of 300 nm. Show that this corresponds to a value of about 10 000 K for the surface temperature of Vega.

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(ii) State the assumption made in your answer to (b)(i).

.....

(2)

(c) State the spectral class to which Vega belongs, giving a reason for your answer.

.....

.....

(1)
(Total 7 marks)

11. (a) Define

(i) apparent magnitude,

.....

.....

(ii) absolute magnitude.

.....

.....

(2)

(b) Bellatrix and Elinath are two stars with the same apparent magnitude. The distance from the Earth to Bellatrix is 470 light years and its absolute magnitude is –4.2.

(i) Calculate the distance to Bellatrix in parsecs.

.....

.....

(ii) Calculate the apparent magnitude of Bellatrix.

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.....

(iii) Elinath has an absolute magnitude of –3.2. State, giving a reason, which of the two stars is closer to the Earth.

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.....

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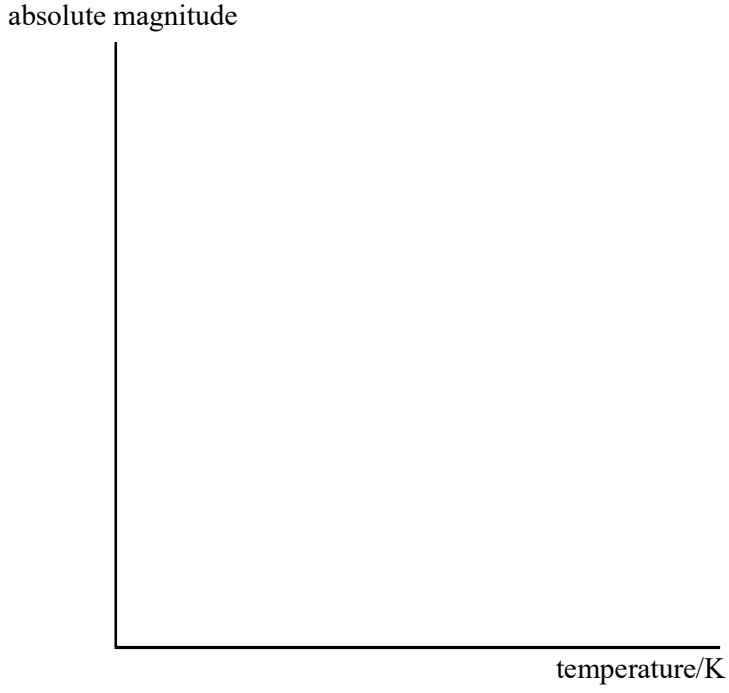
(6)
(Total 8 marks)

12. (a) Draw a Hertzsprung-Russell diagram on the axes below. Label the maximum and minimum values of both absolute magnitude and temperature on the axes. Also label the positions of the main sequence, dwarf stars and giant stars.



(4)

(b) The spectral class of four stars is given in the table.

star	spectral class
Alnitak	O
Sirius	A
Sun	G
Antares	M

The spectrum of each star contains absorption lines. State what produces the main absorption lines in each case.

Alnitak

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Sirius

.....

.....

Sun

.....

.....

Antares

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.....

(2)

(c) Antares and Alnitak have similar absolute magnitudes. State and explain which of the two has the larger diameter.

You may be awarded marks for the quality of written communication in your answer.

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(3)
(Total 9 marks)

13. (a) Betelgeuse is a red supergiant star with a mass approximately ten times greater than that of the Sun. Eventually it is quite likely that Betelgeuse will become a *supernova*, leaving a *neutron star* or perhaps a *black hole*.

State a significant property of a

(i) supernova,

.....

.....

(ii) neutron star,

.....

.....

(iii) black hole.

.....

.....

(3)

(b) Calculate the Schwarzchild radius for a black hole whose mass is ten times greater than that of the Sun.

.....

.....

(2)
(Total 5 marks)

14. (a) Explain what is meant by *light year* and *parsec.*

(i) light year

.....

.....

(ii) parsec

.....

.....

(2)

(b) 95 Herculis is approximately 450 light years from the Earth. It is a binary system consisting of two stars each of apparent magnitude 5.1. One star belongs to spectral class A and the other to spectral class G.

(i) Calculate the absolute magnitude of either of the stars of 95 Herculis.

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(ii) To which spectral class does the hotter star belong? Justify your answer.

.....

.....

.....

(iii) To which spectral class does the smaller star belong? Justify your answer.

(5)

(c) The two stars of 95 Herculis are separated by an angle of 1.8×10^{-3} degrees. Calculate the minimum diameter of an aperture which would just allow these stars to be resolved.
wavelength of the light = 5.0×10^{-7} m

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.....

(2)
(Total 9 marks)

15. The Earth's atmosphere absorbs electromagnetic radiation of certain wavelengths. Detectors on the surface of the Earth are largely restricted to the visible and radio regions.

(a) (i) On the axes below, draw the black body radiation curve for the Sun.

(ii) Mark on the wavelength axis the region affected by the atmosphere's absorption of ultra violet radiation.

(iii) What is responsible for this absorption?

.....

(iv) What effect can this absorption have on the measured temperature of a star? Explain your answer.

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(4)

(b) The atmosphere has little effect on radio waves between 30 MHz and 300 GHz. This radio window was first exploited in 1946 when a short pulse of radio waves of wavelength 2.7 m was transmitted from the Earth and reflected back by the Moon.

(i) Show that the frequency of the transmitted waves falls within the radio window.

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(ii) The experimenters had to take into account the relative movement of the Earth and Moon when tuning the receiver. The maximum difference between the frequency of the detected and transmitted waves was 300 Hz.

What is the name of this effect?

.....

(iii) Calculate the relative velocity of the Earth and Moon when the frequency of the received signal was 300 Hz greater than the transmitted frequency.

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(5)
(Total 9 marks)

16. (a) (i) On the axes below draw the Hertzsprung-Russell (H-R) diagram labelling the main sequence stars, dwarf stars and giant stars. Complete the horizontal axis by labelling the spectral classes.

(ii) On the H-R diagram, mark with an **X** the current position of the Sun and draw a line to represent the evolution of the Sun, from its formation to its eventual state as a white dwarf.

(4)

(b) Matar is a star in the same spectral class as the Sun.

(i) State **two** properties common to Matar and the Sun.

.....

.....

(ii) The distance to Matar is 330 light years. What is this distance in parsec?

.....

(iii) The apparent magnitude of Matar is 2.9. Calculate its absolute magnitude.

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(iv) Which is the larger star, Matar or the Sun? Explain your answer.

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(6)

(Total 10 marks)

17. **Figure 1** shows the black body radiation curves for three stars, labelled P, Q and R.

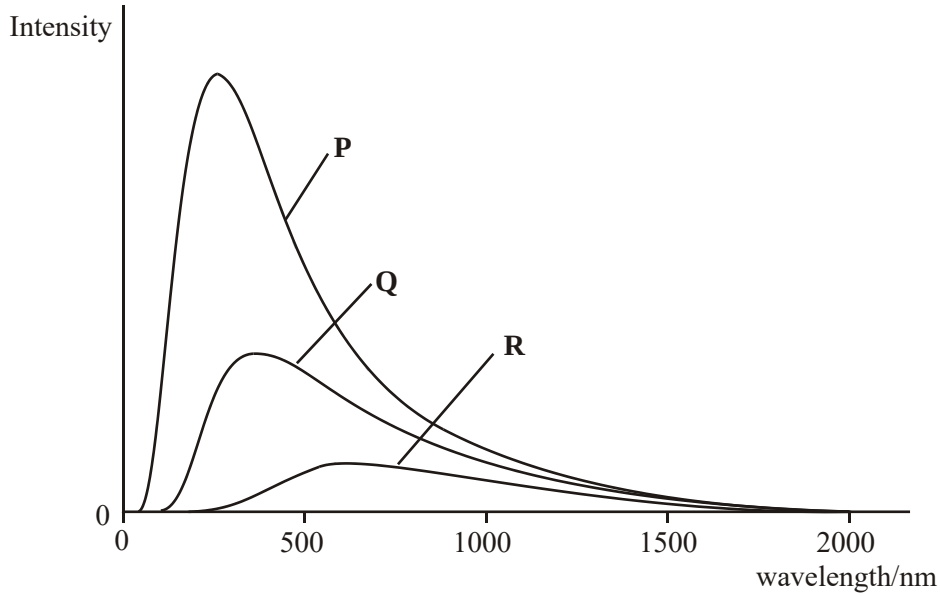

Figure 1

(a) (i) State and explain, without calculation, which one of the three stars is the hottest.

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.....

.....

(ii) Calculate the black body temperature of the hottest star.

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(3)

(b) More detailed analysis of the hottest star's spectrum revealed the presence of Hydrogen Balmer absorption lines.

(i) For which two spectral classes are these lines the prominent feature?

.....

(ii) Describe how these absorption lines are produced in the spectrum of a star.

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(4)
(Total 7 marks)

18. (a) (i) State what is meant by the *event horizon* of a black hole.

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(ii) Write down the equation for the radius of the event horizon of a black hole, and define each term in the equation.

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(2)

(b) Calculate the mass of a black hole with a Schwarzchild radius equal to the radius of the Earth.

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(2)
(Total 4 marks)

19. (a) The table summarises the properties of five of the stars in the constellation of Cassiopeia.

name	**absolute magnitude**	**apparent magnitude**	**spectral class**
Achird	4.6	3.5	G
Chaph	1.9	2.3	F
Ruchbah	0.24	2.7	A
Segin	–2.4	3.4	B
Shedir	–0.9	2.2	K

Explaining your answer in each case, state which star

(i) is the hottest,

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.....

.....

(ii) is likely to appear orange in colour,

.....

.....

.....

(iii) appears the brightest from Earth,

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.....

.....

(iv) is less than 10 pc away from the Earth.

.....

.....

.....

(4)

(b) The constellation Cassiopeia contains another star with an apparent magnitude of 2.2, absolute magnitude of –4.6 and a surface temperature of 12 000 K. Calculate, for this star,

(i) its distance from the Earth,

.....

.....

.....

(ii) the peak wavelength in its black body radiation curve.

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.....

(3)
(Total 7 marks)

20. (a) Define the *absolute magnitude* of a star.

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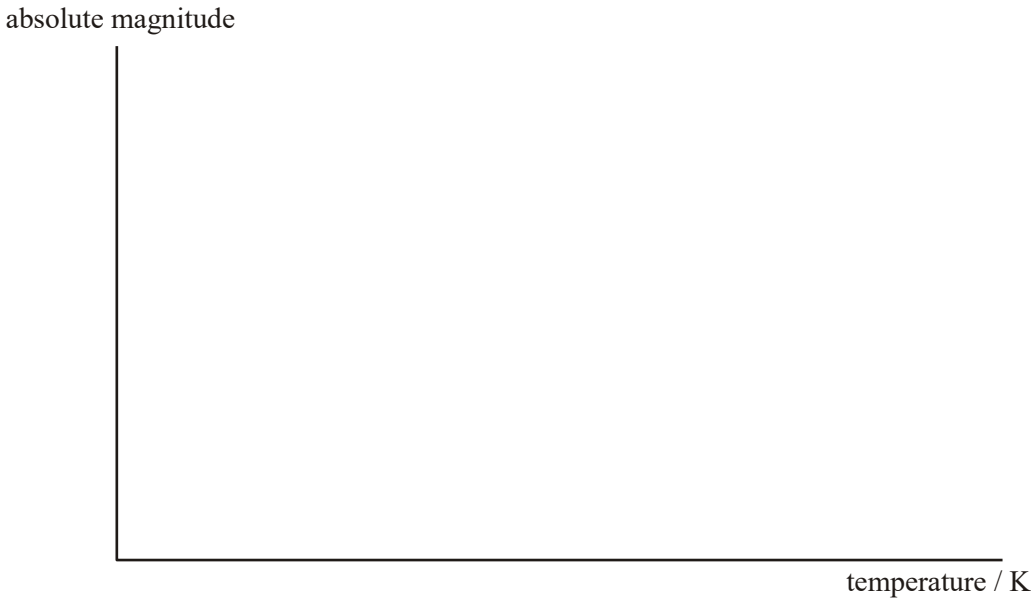
.....

(1)

(b) The figure below shows the axes of a Hertzsprung-Russell (H-R) diagram.



(i) On each axis indicate a suitable range of values.

(ii) Label with an S the current position of the Sun on the H-R diagram.

(iii) Label the positions of the following stars on the H-R diagram:

(1) star W, which is significantly hotter and brighter than the Sun,

(2) star X, which is significantly cooler and larger than the Sun,

(3) star Y, which is the same size as the Sun, but significantly cooler,

(4) star Z, which is much smaller than the Sun, and has molecular bands as an important feature in its spectrum.

(7)
(Total 8 marks)

21. Treated as a single source, the Andromeda galaxy has an apparent magnitude of 3.54 and an absolute magnitude of –20.62.

(a) Calculate the distance to the Andromeda galaxy.

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(2)

(b) The Andromeda galaxy is believed to be approaching the Milky Way at a speed of 105 km s^{-1}.
Calculate the wavelength of the radio waves produced by atomic hydrogen which would be detected from a source approaching the observer at a speed of 105 km s^{-1}.

wavelength of atomic hydrogen measured in a laboratory = 0.21121 m.

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.....

(2)

(c) Some astronomers believe the Andromeda galaxy may collide with the Milky Way in the distant future. Estimate a time, in s, which will elapse before a possible impact with the Milky Way.

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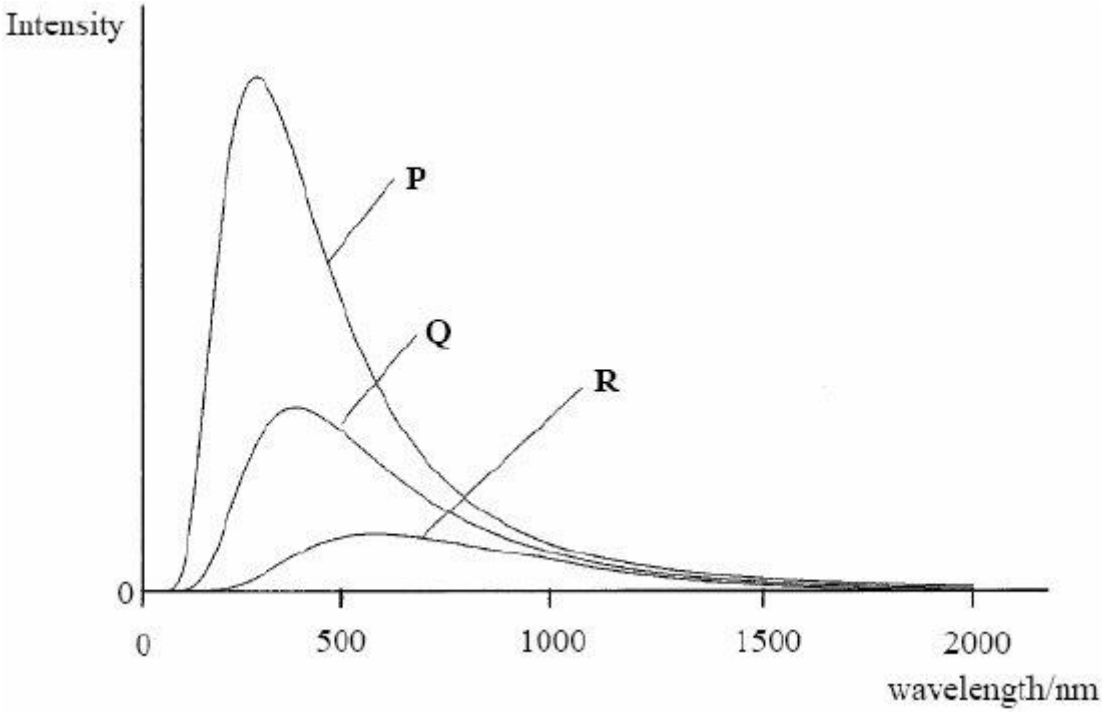
(2)
(Total 6 marks)

22. The diagram below shows the black body radiation curves for three stars, labelled P, Q and R.



(a) (i) State and explain, without calculation, which one of these three stars is the hottest.

.....

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.....

.....

(ii) Calculate the black body temperature of the hottest star.

Temperature =.....

(3)

(b) More detailed analysis of the hottest star's spectrum revealed the presence of Hydrogen Balmer absorption lines.

(i) For which two spectral classes are these lines the prominent feature?

.....

(ii) Describe how these absorption lines are produced in the spectrum of a star.

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(4)
(Total 7 marks)

23. (a) Define the *absolute magnitude* of a star.

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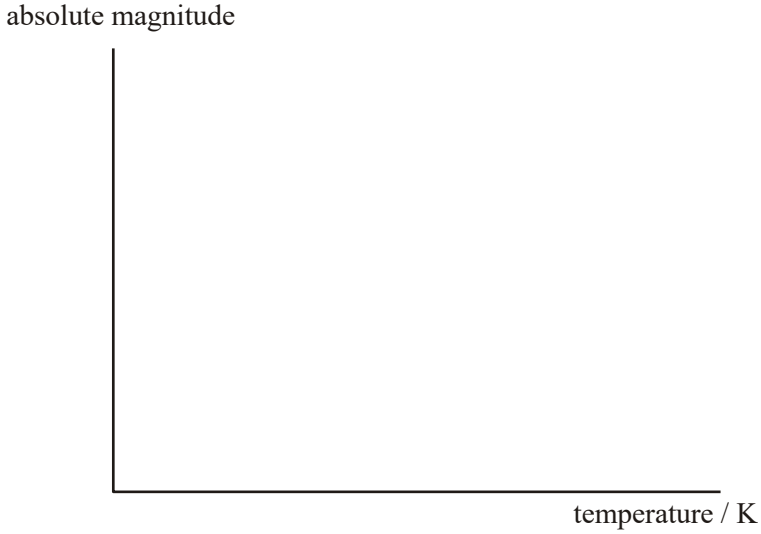
(1)

(b) The diagram below shows the axes of a Hertzsprung-Russell (H-R) diagram.



(i) On each axis indicate a suitable range of values.

(ii) Label with an S the current position of the Sun on the H-R diagram.

(iii) Label the positions of the following stars on the H-R diagram:

(1) star W, which is significantly hotter and brighter than the Sun.

(2) star X, which is significantly cooler and larger than the Sun.

(3) star Y, which is the same size as the Sun, but significantly cooler.

(4) star Z, which is much smaller than the Sun, and has molecular bands as an important feature in its spectrum.

(7)

(Total 8 marks)