1. (a) Define power.

....

.... **(1)**

State an appropriate unit for power.

.... **(1)**

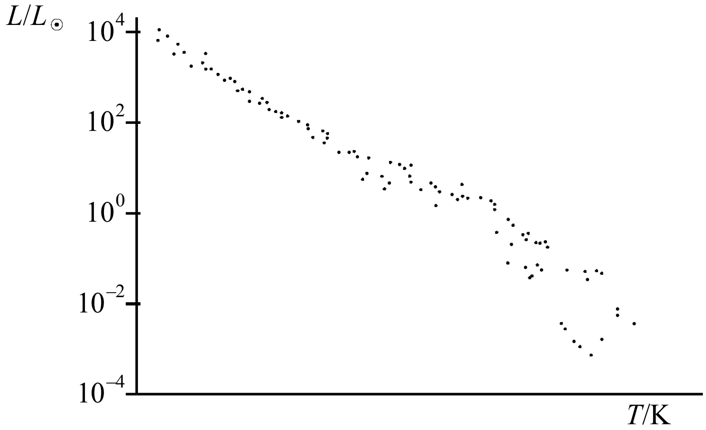
Express this unit in terms of base units.

....

....

.... **(2)**

(b) A Hertzsprung-Russell diagram showing the main sequence is drawn below. Luminosity of the Sun = $\boldsymbol{L_\odot}$.



Draw a circle on the diagram showing the region where the Sun is located. Label this circle S. Draw another circle showing the region where the most massive main sequence stars are located. Label this circle M. **(2)**

Indicate on the temperature axis the approximate temperatures of the coolest and of the hottest stars. **(2)**

Explain why large mass stars spend less time than the Sun on the main sequence.

....

....

.... **(2)**

The luminosity of the Sun is 3.9×10^{26} W. Calculate the rate at which mass is being converted to energy in the Sun.

....

....

....

Rate = ...

(3)

(c) Charge coupled devices can have an efficiency as great as 70% compared with photographic film which has an efficiency of less than 5%. State two advantages of this greater efficiency.

Advantage 1 ....

....

Advantage 2 ....

....

(2)

Explain why astronomical telescopes are sometimes launched into space.

....

....

....

....

(2)

(d) Observations with a radio telescope in 1967 detected signals from a mysterious source which was called a pulsar.

What type of star is a pulsar?

....

(1)

What was unusual about the signals?

....

....

....

(2)

Pulsars emit radio waves continuously. Explain why the signals detected on Earth are not continuous. You may be awarded a mark for the clarity of your answer.

....

....

....

....

(3)

(e) Read the short passage below and answer the questions about it.

> Cepheid variables are faint red giants whose brightness changes periodically. Their periodic changes in luminosity are the result of periodic pulsations of their giant bodies. A simple relationship exists between the periods of these pulsations and the luminosities of the stars. The greater the luminosity, the longer the period of pulsation. This relationship has proved very useful for measuring the distances of stars which are too far away to show a parallax displacement. By measuring the pulsation period of a star its luminosity can he determined. This, combined with a measurement of the intensity at the Earth's surface, enables the distance to the star to he calculated.
>
> [Adapted from *The Creation of the Universe* by George Gamow]

What is meant by the following terms used in the passage?

Red giants: ....

....

....

....

Parallax displacement : ....

....

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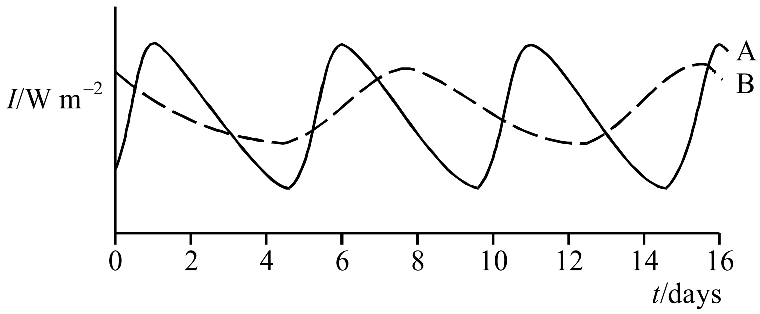
....

....

(3)

The curves below are plots of intensity against time for two Cepheid variable stars, A and B. These are known as light curves,



Estimate the period of the pulsations of star A.

....

(1)

What can he deduced about the luminosity of star B?

....

(1)

Since the average intensities of stars A and B are similar, what can be deduced about the distances of the two stars from the Earth? Give the reasoning which led to your answer.

....

....

....

....

(2)

Name the two forces, one which causes a star to contract and one which causes it to expand, which must be repeatedly out of balance in a Cepheid variable.

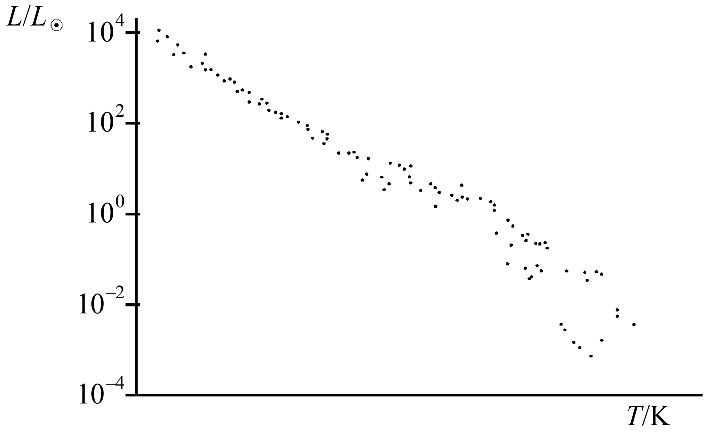
....

....

....

(2)
(Total 32 marks)

2. A Hertzsprung-Russell diagram showing the main sequence is drawn below. Luminosity of the Sun = $\boldsymbol{L_\odot}$.



Draw a circle on the diagram showing the region where the Sun is located. Label this circle S. Draw another circle showing the region where the most massive main sequence stars are located. Label this circle M.

(2)

Indicate on the temperature axis the approximate temperatures of the coolest and of the hottest stars.

(2)

Explain why large mass stars spend less time than the Sun on the main sequence.

....

....

....

(2)

The luminosity of the Sun is 3.9×10^{26} W. Calculate the rate at which mass is being converted to energy in the Sun.

....

....

....

Rate = ...

(3)

(Total 9 marks)

3. Charge coupled devices can have an efficiency as great as 70% compared with photographic film which has an efficiency of less than 5%. State two advantages of this greater efficiency.

Advantage 1 ....

....

Advantage 2 ....

....

(2)

Explain why astronomical telescopes are sometimes launched into space.

....

....

....

....

(2)
(Total 4 marks)

4. Observations with a radio telescope in 1967 detected signals from a mysterious source which was called a pulsar.

What type of star is a pulsar?

....

(1)

What was unusual about the signals?

....

....

....

(2)

Pulsars emit radio waves continuously. Explain why the signals detected on Earth are not continuous. You may be awarded a mark for the clarity of your answer.

....

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....

....

(3)
(Total 6 marks)

5. Read the short passage below and answer the questions about it.

> Cepheid variables are faint red giants whose brightness changes periodically. Their periodic changes in luminosity are the result of periodic pulsations of their giant bodies. A simple relationship exists between the periods of these pulsations and the luminosities of the stars. The greater the luminosity, the longer the period of pulsation. This relationship has proved very useful for measuring the distances of stars which are too far away to show a parallax displacement. By measuring the pulsation period of a star its luminosity can he determined. This, combined with a measurement of the intensity at the Earth's surface, enables the distance to the star to he calculated.
>
> [Adapted from *The Creation of the Universe* by George Gamow]

What is meant by the following terms used in the passage?

Red giants:..

....

....

....

Parallax displacement:...

....

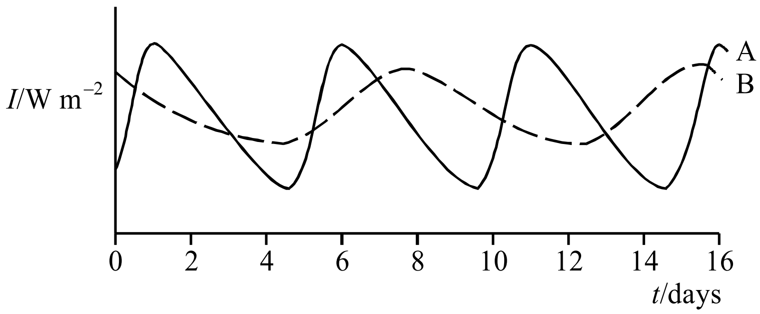
....

....

....

(3)

The curves below are plots of intensity against time for two Cepheid variable stars, A and B. These are known as light curves,



Estimate the period of the pulsations of star A.

....

(1)

What can he deduced about the luminosity of star B?

....

(1)

Since the average intensities of stars A and B are similar, what can be deduced about the distances of the two stars from the Earth? Give the reasoning which led to your answer.

....

....

....

....

(2)

Name the two forces, one which causes a star to contract and one which causes it to expand, which must be repeatedly out of balance in a Cepheid variable.

....

....

....

....

(2)
(Total 9 marks)

6. (a) Name the two main wavelength bands of the electromagnetic spectrum which are used for terrestrial astronomy.

....

(2)

State and explain *two* different benefits of observing stars and galaxies from above the Earth's atmosphere.

....

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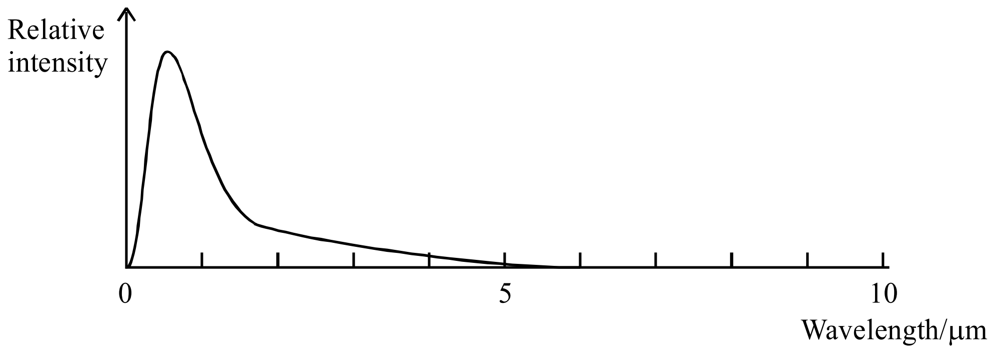
(4)

(b) The graph shows the relative intensity of the energy distribution in the spectrum of a body radiating at a temperature of 6000 K (the approximate temperature of the Sun).



Use Wien's law, $\lambda_{max}T = 3.9 \times 10^{-3}$ m K, to estimate the wavelength at which the intensity of radiation from the Earth is a maximum.

....

....

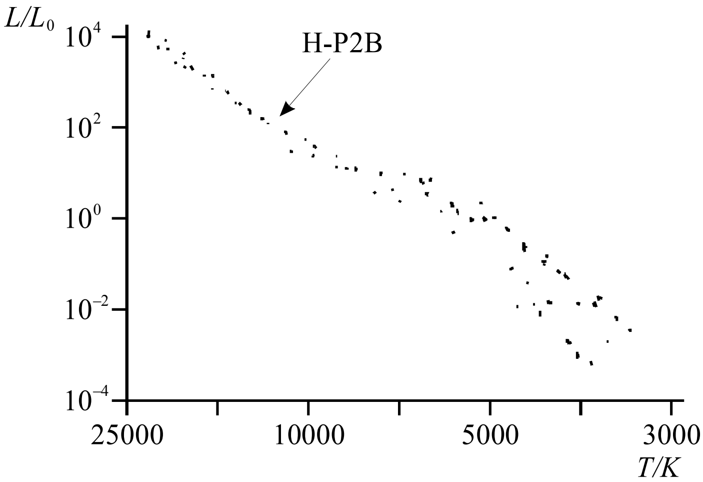
....

(2)

Add a second curve to the graph to show the approximate energy distribution in the radiation emitted by the Earth in the range 0 – 10 µm.

(2)

(c) Here is a Hertzsprung-Russell diagram showing the main sequence.



Mark regions on the diagram where you would find (i) giant stars (ii) white dwarfs.

(2)

L_0, the luminosity of the Sun, is 3.9×10^{26} W. Estimate the temperature of the Sun.

....

(1)

Use the graph to estimate the luminosity of the star H-P 2B.

....

....

(2)

Use the Stefan-Boltzmann law to calculate the surface area, and hence the radius of H-P 2B.

....

....

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....

....

Surface area =...

Radius =...

(4)

(d) Our Sun is on the main sequence. Outline its past and expected life story, starting from the time it was first on the main sequence. You may be awarded a mark for the clarity of your answer.

....

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....

(Total 4 marks)

(e) After thousands and thousands of measurements, first with photographic plates and then with charged-coupled devices, we find a major key to stellar astrophysics, a strict relation between luminosity and mass for main sequence stars. Luminosity L climbs roughly as the mass m raised to the power 3.5. A star like Sirius A, 2.3 times the solar mass, is some 20 times as bright. The main sequence is really a mass sequence. The Sun is in the middle of the mass range. The observed masses run from a minimum of 8% that of the Sun to over 120 times the solar mass at the top end.

[Adapted from J B Kaler: *Stars*, W H Freeman 1992.]

(i) What, roughly, are the sizes of;

individual grains in a photographic emulsion,
pixels in a CCD?

....

....

State *two* advantages of using CCDs rather than photographic plates in astronomical investigations.

....

....

....

....

....

....

(4)

(ii) Write an equation linking luminosity and mass for main sequence stars.

....

....

Use your equation to confirm that Sirius A is about 20 times as bright as the Sun.

....

....

....

....

(3)

(iii) Explain why there is a minimum to the mass of a star.

....

....

....

....

(2)
(Total 32 marks)

7. Name the two main wavelength bands of the electromagnetic spectrum which are used for terrestrial astronomy.

....

(2)

State and explain *two* different benefits of observing stars and galaxies from above the Earth's atmosphere.

....

....

....

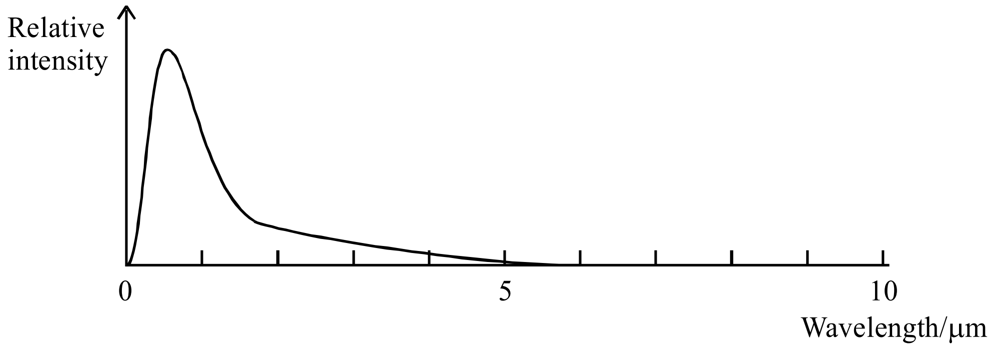
....

....

....

(4)
(Total 6 marks)

8. The graph shows the relative intensity of the energy distribution in the spectrum of a body radiating at a temperature of 6000 K (the approximate temperature of the Sun).



Use Wien's law, $\lambda_{max}T = 3.9 \times 10^{-3}$ m K, to estimate the wavelength at which the intensity of radiation from the Earth is a maximum.

....

....

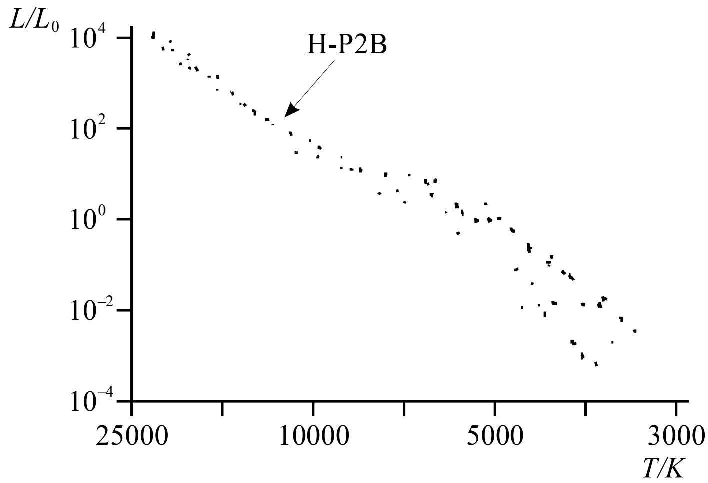
....

(2)

Add a second curve to the graph to show the approximate energy distribution in the radiation emitted by the Earth in the range 0 – 10 μm.

(2)
(Total 4 marks)

9. Here is a Hertzsprung-Russell diagram showing the main sequence.



Mark regions on the diagram where you would find (i) giant stars (ii) white dwarfs.

(2)

L_0, the luminosity of the Sun, is 3.9×10^{26} W. Estimate the temperature of the Sun.

....

(1)

Use the graph to estimate the luminosity of the star H-P 2B.

....

....

....

(2)

Use the Stefan-Boltzmann law to calculate the surface area, and hence the radius of H-P 2B.

....

....

....

....

....

....

Surface area =………………………………………………………

Radius =………………………………………………………

(4)

(Total 9 marks)

10. Our Sun is on the main sequence. Outline its past and expected life story, starting from the time it was first on the main sequence. You may be awarded a mark for the clarity of your answer.

....

....

....

....

....

....

(Total 4 marks)

11. After thousands and thousands of measurements, first with photographic plates and then with charged-coupled devices, we find a major key to stellar astrophysics, a strict relation between luminosity and mass for main sequence stars. Luminosity L climbs roughly as the mass m raised to the power 3.5. A star like Sirius A, 2.3 times the solar mass, is some 20 times as bright. The main sequence is really a mass sequence. The Sun is in the middle of the mass range. The observed masses run from a minimum of 8% that of the Sun to over 120 times the solar mass at the top end.

[Adapted from J B Kaler: *Stars*, W H Freeman 1992.]

(a) What, roughly, are the sizes of;

individual grains in a photographic emulsion,
pixels in a CCD?

....

....

State *two* advantages of using CCDs rather than photographic plates in astronomical investigations.

....

....

....

....

....

....

....

....

(4)

(b) Write an equation linking luminosity and mass for main sequence stars.

....

....

Use your equation to confirm that Sirius A is about 20 times as bright as the Sun.

....

....

....

....

(3)

(c) Explain why there is a minimum to the mass of a star.

....

....

....

....

(2)
(Total 9 marks)

12. (a) State two similarities and one difference between light and radio waves.

Similarity 1 ....

Similarity 2 ....

Difference ....

(3)

(b) Stars β Ori and α Cet have temperatures of approximately 11 000 K and 3600 K respectively. Calculate the wavelength at which the intensity of radiation from each star is a maximum. Give your answers in nanometres.

β Ori ....

....

α Cet ....

....

(3)

Use the Stefan-Boltzmann law to calculate the power emitted per square metre of surface, measured in W m^{-2} , for β Ori.

....

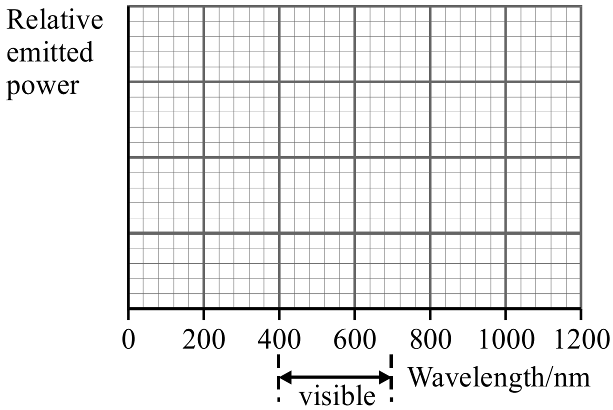
....

....

(2)

The power emitted per square metre of surface for α Cet = 1.0×10^7 W m^{-2}.

Sketch two graphs on the axes below, showing how this emitted power is distributed over different wavelengths for each star. Label your graphs Ori and Cet.



(3)

The visible spectrum extends from approximately 400 nm to 700 nm. Use your graphs to explain why β Ori is a bluish star, while α Cet is reddish.

....

....

....

....

(2)

(c) Draw a labelled diagram to illustrate the principle of how the distance to a nearby star can be measured using the annual parallax method.

(4)

Why is this method only suitable for nearby stars?

....

....

(1)

(d) Stars of more than eight solar masses may undergo a spectacular supernova explosion. Outline the processes that take place in the star that result in such an event. You may be awarded a mark for the clarity of your answer.

....

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....

....

....

(4)

What may happen to the core remnant from such an event?

....

....

(1)

(e) Read the short passage below and answer the questions about it.

> The Sun is a typical main sequence star. The conversion of hydrogen to helium in its core where the temperature is $\approx 15 \times 10^6$ K releases energy. This energy is chiefly in the form of X-rays of wavelength 0.2 nm – 1 nm and is transported to the Sun's surface by radiation and convection. It takes about 2×10^5 years for the energy to reach the Sun's surface. The radiative zone extends from the centre to $\frac{3}{4}$ of the solar radius. In this zone X-rays are repeatedly absorbed and re-emitted by gas atoms. This happens at approximately 1 mm intervals. The convective zone ranges from $\frac{3}{4}$ solar radius outwards. In this zone the gas is cooler and even more opaque to X-rays so energy is transported by large-scale movement of the gas itself.
> [Adapted from *Life and Death of Stars* by Dr L J Smith]

Sketch a Hertzsprung-Russell diagram to show what is meant by the term main sequence.

(3)

The radius of the Sun is 7×10^8 m. Calculate the time it would take for X-rays to reach the surface of the Sun if they travelled there directly at a speed of 3×10^8 in s^{-1}.

....

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(2)

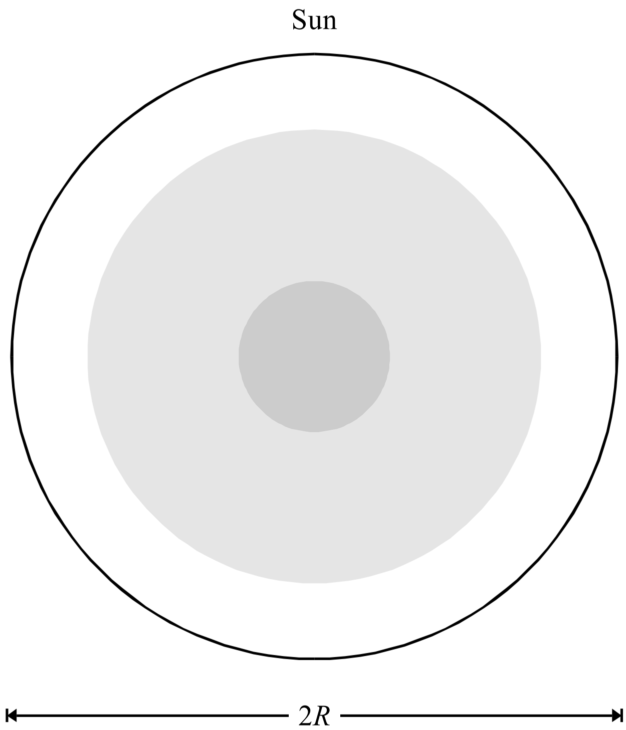
Why is convection the main method of energy transfer in the outer region of the Sun?

....

....

(1)

Label the diagram below to summarise the transport of energy to the Sun's surface.



(3)
(Total 32 marks)

13. (a) State two advantages of positioning an optical telescope on the top of a mountain.

1 ....

....

2 ....

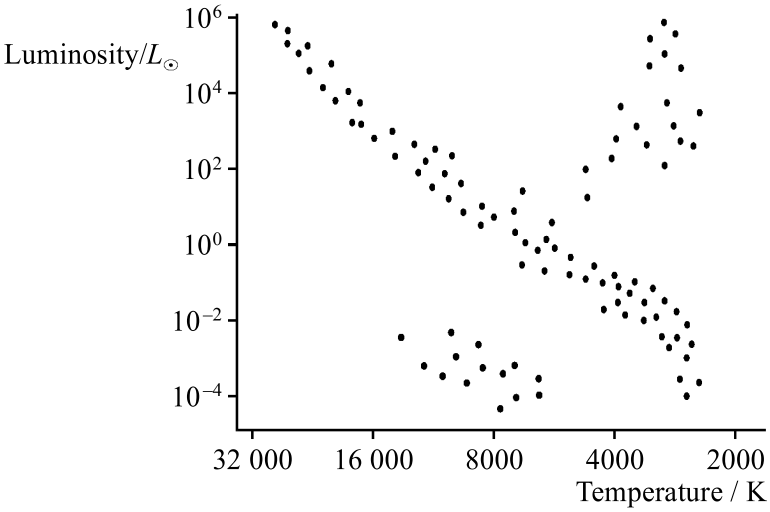
....

(2)

(b) The table shows the properties of three stars.

	Star	Luminosity/$L_{\odot}$	Temperature/K
A	α Ori	6×10^{4}	3500
B	Procy B	3×10^{-4}	7000
C	β Per	2×10^{2}	12 000

On the Hertzsprung-Russell diagram below, mark with an x_A, x_B and x_C the approximate position of each of the three stars.



(1)

State whether each star is a main sequence star, a red giant or a white dwarf.

α Ori ....

Procy B ....

β Per ....

(3)

Use the Stefan-Boltzmann law to calculate the surface area and hence the radius of α Ori.
(Luminosity of the Sun = 3.8×10^{26} W.)

....

....

....

....

....

Surface area = ...

....

....

Radius = ...

(5)

(c) Explain why the term **light year** is a measure of distance and not of time.

....

....

(1)

Show that the light year is equivalent to a distance of approximately 9×10^{15} m.

....

....

....

(2)

Explain why the annual parallax method is only suitable for measuring the distance to nearby stars.

....

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....

(3)

(d) What is a supernova?

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....

Describe briefly what happens during the formation of a supernova. You may be awarded a mark for the clarity of your answer.

....

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(5)

What are the two possible fates for the central core remnant from a supernova explosion?

....

....

(2)

(e) Read the short passage below and answer the questions about it.

Brown dwarfs are faint objects which radiate mainly in the near infra-red part of the spectrum. Analysing the spectra of faint objects can reveal whether they are stars or brown dwarfs. Gliese 570D one of the coolest brown dwarfs detected, has a surface temperature of about 750 K. The spectrum of Gliese 570D shows the presence of methane, the molecules of which break apart in the hotter atmosphere of stars. The spectrum of another brown dwarf PPL 15 indicates the presence of lithium. All stars achieve a sufficiently high core temperature to convert hydrogen to helium. Therefore even a low mass star would consume whatever lithium it originally had in approximately 100 million years, since this nuclear reaction occurs at a slightly lower temperature than hydrogen “burning”.

Use Wien’s law to show that Gliese 570D radiates mainly in the infra-red region of the electromagnetic spectrum. (The visible reaction extends from 400 nm to 700 nm.)

....

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....

....

(3)

Why are brown dwarfs cooler than 750 K extremely difficult to detect?

....

....

....

What nuclear process distinguishes stars from brown dwarfs?

....

....

(1)

Lithium is destroyed in the core of a star when a proton collides with a nucleus of ${}^{7}_{3}\text{Li}$ creating two helium nuclei, ${}^{4}_{2}\text{He}$. Write a nuclear equation for this reaction.

....

(2)

Why might a very young low mass star be mistaken for a brown dwarf?

....

....

(1)
(Total 32 marks)

14. (a) The intensity of solar radiation at the top of the Earth's atmosphere is 1.4 kW m^{-2}. The Sun's average distance from the Earth is 1.5×10^{11} m.

Show that the luminosity of the Sun is approximately 4×10^{26} W.

....

....

....

....

(3)

Why is the intensity at the top of the Earth's atmosphere used in this calculation?

....

....

(1)

The Sun's energy is produced when hydrogen 'burns' to form helium. Four protons are required to make each helium nucleus. Use the data below to estimate the energy released for each helium nucleus created. (Your answer will be only approximate as it ignores the positrons which are also released in the process.)

Data: mass of proton = 1.67×10^{-27} kg
mass of helium nucleus = 6.64×10^{-27} kg

....

....

....

Energy released = ...

(4)

Show that the number of helium nuclei created per second in the Sun is approximately 1×10^{38}.

....

....

....

(1)

Hence estimate the mass of hydrogen burned per second in the Sun.

....

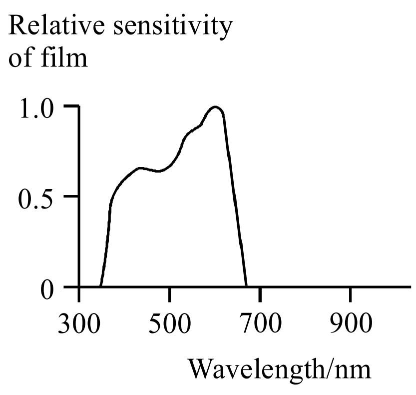
....

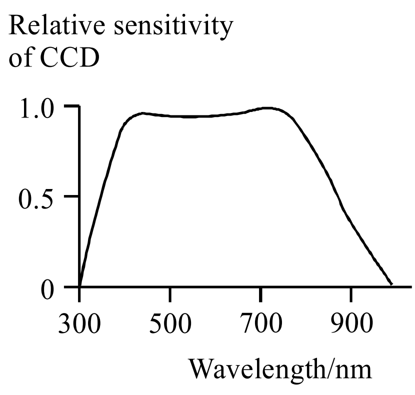
....

Mass of hydrogen = ...

(2)

(b) The graphs show the sensitivity of a particular brand of photographic film and that of a charge coupled device, CCD, to different parts of the electromagnetic spectrum.





The surface temperature of a star can be calculated once the wavelength of the peak of its spectrum (λ_{max}) is known. Use the graphs to explain why photographic film would be less suitable than CCDs for determining λ_{max} of a star which radiates mainly in the visible region (400 nm – 700 nm) of the electromagnetic spectrum.

....

....

....

....

....

(3)

State one other advantage of using CCDs suggested by these graphs.

....

(1)

(c) State what happens to the hydrogen 'burning' process in a star as it moves off the main sequence to become a red giant.

....

....

....

(2)

Why is a red giant more luminous than the main sequence star from which it originated, even though its temperature is lower?

....

....

(1)

(d) Describe how observations of Cepheid variable stars are used to estimate the distance to nearby galaxies. You may be awarded a mark for the clarity of your answer.

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(5)

(e) Read the short passage below and answer the questions about it.

> In a simple binary system two stars move in circular orbits of different radii about a common centre. The two stars take the same time T to complete one revolution. If the binary system is viewed more or less edge-on the stars periodically pass in front of one another, reducing the amount of light that reaches us. Such a system is called an eclipsing binary and can be detected from its light curve, which is a plot showing how the observed light intensity varies with time. Once the orbital period T has been determined the total mass M of the binary system can be calculated from the relationship $M = 4\pi^2 d^3 / GT^2$ where d is the sum of the radii and G is the gravitational constant.
>
> [Adapted from TRUMP *Astrophysics Project*]

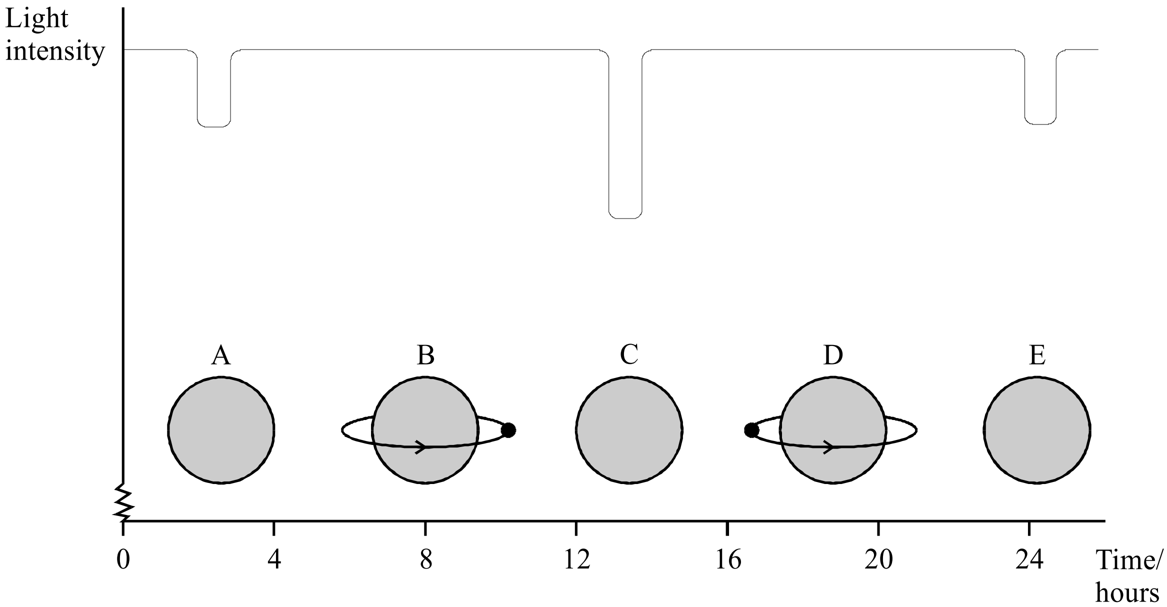
Explain the meaning of the term **binary system.**

....

....

(1)

The light curve for an eclipsing binary consisting of a small very bright star and a much larger star is shown below. The system is being viewed edge-on. Diagrams B and D (not to scale) show the relative positions of the small and large star at two times between the dips in the light curve.



Complete diagrams A, C and E to show the positions of the small bright star at the times of the dips in the light curve.

(2)

Explain why the dip in the curve at A is smaller than the dip at C.

....

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....

(2)

Estimate the orbital period of this binary.

....

(1)

Approximately how long does it take the small star to cross the disc of the larger one?

....

(1)

On the light curve above show how the observed light intensity varies with time when this system is viewed perpendicular to the plane of the orbits.

(2)

(Total 32 marks)

15. (a) The diagram shows part of the range of unit prefixes. Complete the diagram below by filling in the empty boxes.

		milli			giga
	10^{-6}	10^{-3}	10^{3}		10^{9}

(4)

(b) When a star moves off the main sequence It initially becomes a red giant. Describe the processes occurring which result in it becoming “giant-sized”. You may be awarded a mark for the clarity of your answer.

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....

(4)

Use Wien’s law to explain why these giant stars look red compared with their appearance when they were on the main sequence.

....

....

....

(2)

Use Stefan’s law to explain why a red giant has greater luminosity than when it was a main sequence star.

....

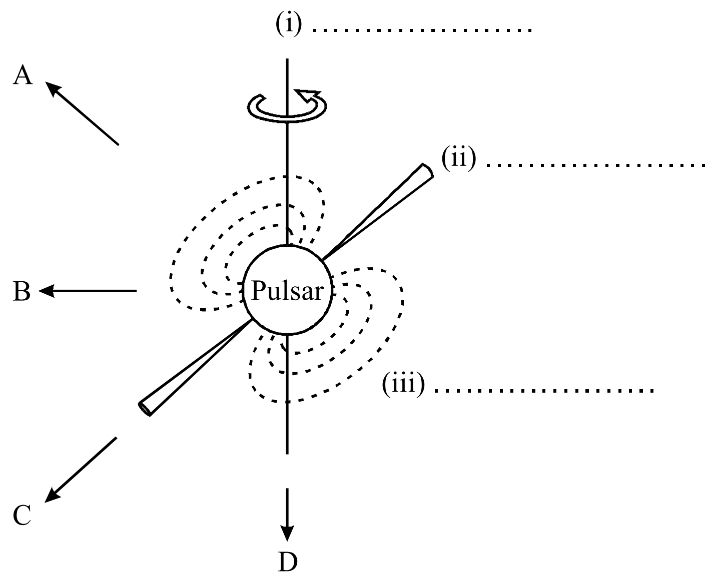
....

....

....

(3)

(c) Label the diagram of a pulsar below in the places (1), (ii), (iii), indicated by the dotted lines.



(3)

What type of star is a pulsar?

....

(1)

In which possible directions, A, B, C, D, might the Earth be situated and receive signals from this pulsar? Explain your answer.

....

....

....

....

....

....

(3)

(d) State two advantages of observing stars using radio telescopes.

1 ....

2 ....

(2)

A radio telescope sensitive to certain frequencies in the GHz range detects a radio flux (intensity) of 1.6×10^{-15} W m^{-2} from the Crab Nebula (one of the brightest radio sources in the sky). What is the radio luminosity of the Crab Nebula in this frequency range? (Distance of the Crab Nebula from Earth = 6.8×10^{19} m.)

....

....

....

....

(4)

(e) Light can be regarded as a stream of tiny packets of energy called photons. The energy of a photon (in joules) is related to the wavelength of the light (in metres) by the expression $E = \dfrac{k}{\lambda}$ where k is a constant equal to 2.0×10^{-25} kg m^3 s^{-2}.

Show that a photon of red light ($\lambda = 700 \times 10^{-9}$ m) has an energy of about 3×10^{-19}J.

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(1)

Hence estimate the number of photons emitted per second by a red giant of luminosity 2.3×10^{31} J s^{-1}.

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(2)

Explain why your answer is only an approximation.

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(1)

State two advantages of CCDs compared with photographic film for recording images of distant stars.

1 ....

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2 ....

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(2)
(Total 32 marks)