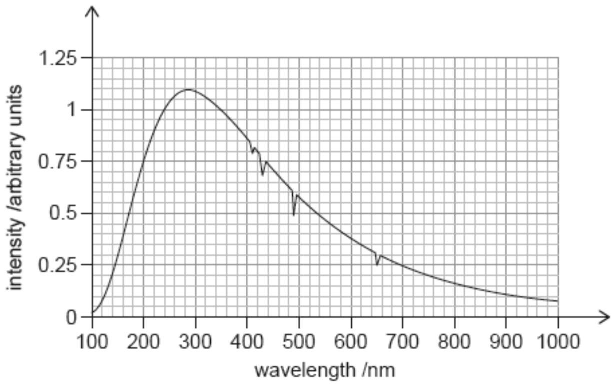
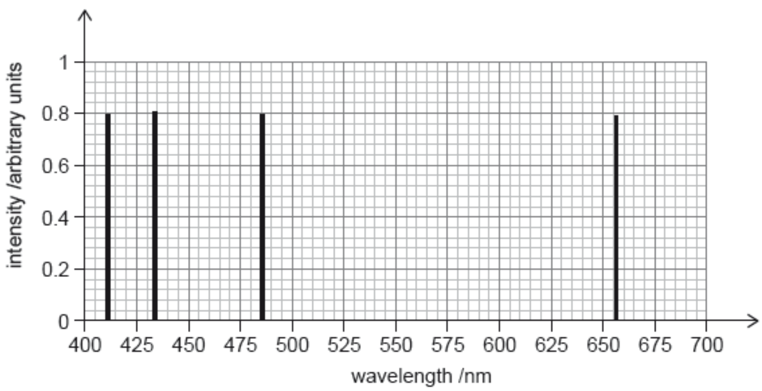
D.2D.3 *[207 marks]*

The graph shows the observed spectrum from star X.



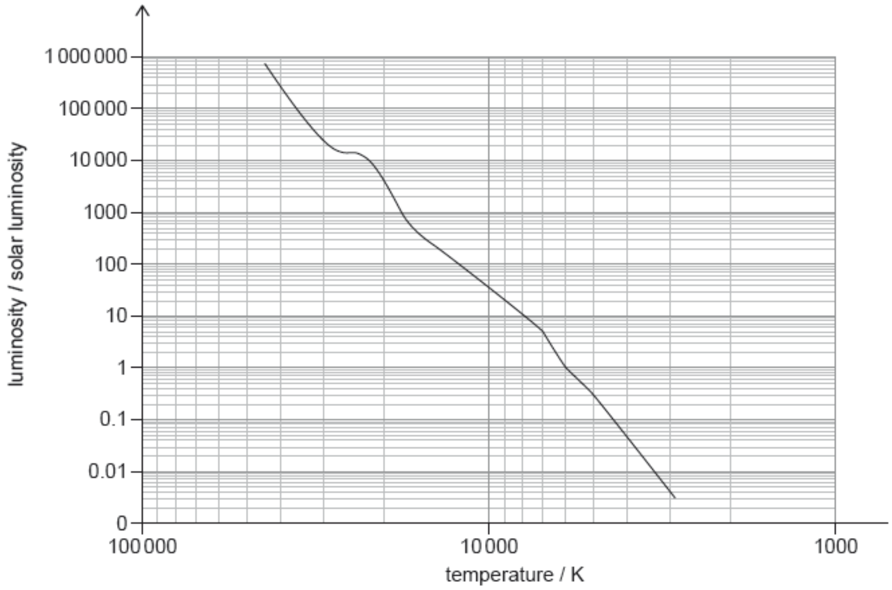
The second graph shows the hydrogen emission spectrum in the visible range.



1a. Suggest, using the graphs, why star X is most likely to be a main sequence star. *[2 marks]*

1b. Show that the temperature of star X is approximately 10 000 K. *[2 marks]*

The following diagram shows the main sequence.



1c. Write down the luminosity of star X (L_X) in terms of the luminosity of the Sun (L_s). *[1 mark]*

1d. Determine the radius of star X (R_X) in terms of the radius of the Sun (R_s). *[3 marks]*

1e. Estimate the mass of star X (M_X) in terms of the mass of the Sun (M_s). *[2 marks]*

1f. Star X is likely to evolve into a stable white dwarf star. *[2 marks]*

Outline why the radius of a white dwarf star reaches a stable value.

The Hubble constant is accepted to be 70 km s^{-1} Mpc^{-1}. This value of the Hubble constant gives an age for the universe of 14.0 billion years.

The accepted value of the Hubble constant has changed over the past decades.

2a. Explain how international collaboration has helped to refine this value. *[1 mark]*

The redshift of a galaxy is measured to be $z = 0.19$.

2b. Estimate, in Mpc, the distance between the galaxy and the Earth. *[2 marks]*

2c. Determine, in years, the approximate age of the universe at the instant when the detected light from the distant galaxy was emitted. *[3 marks]*

3a. Main sequence stars are in equilibrium under the action of forces. Outline how this equilibrium is achieved. *[2 marks]*

3b. A main sequence star P, is 1.3 times the mass of the Sun. Calculate the luminosity of P relative to the Sun. *[1 mark]*

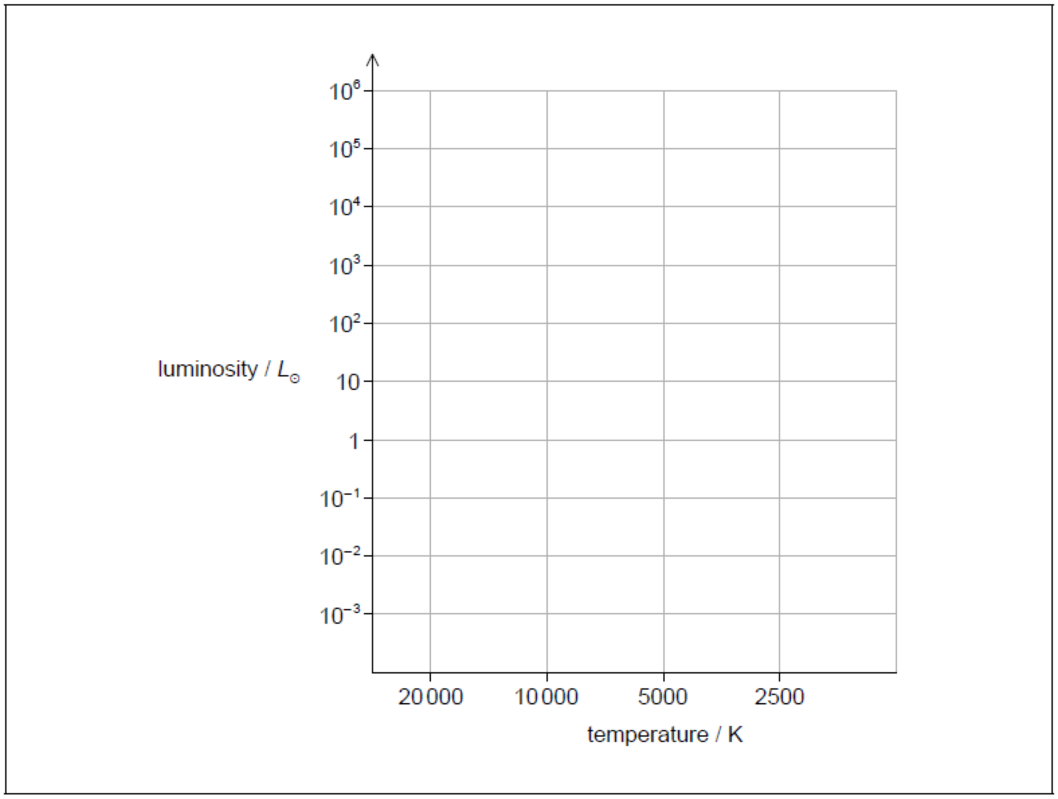
The following data apply to the star Gacrux.

$$\begin{aligned} \text{Radius} &= 58.5 \times 10^9 \text{ m} \\ \text{Temperature} &= 3600 \text{ K} \\ \text{Distance} &= 88 \text{ ly} \end{aligned}$$

3c. The luminosity of the Sun $L_\odot$ is 3.85×10^{26} W. Determine the luminosity of Gacrux relative to the Sun. *[3 marks]*

3d. The distance to Gacrux can be determined using stellar parallax. Outline why this method is not suitable for all stars. *[1 mark]*

A Hertzsprung–Russell (HR) diagram is shown.



On the HR diagram,

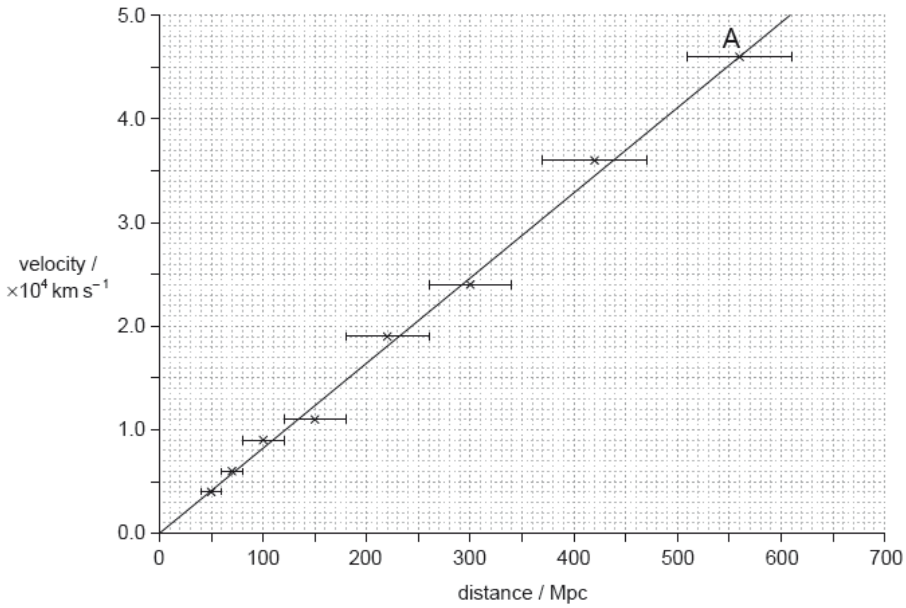
3e. draw the main sequence. *[1 mark]*

3f. plot the position, using the letter P, of the main sequence star P you calculated in (b). *[1 mark]*

3g. plot the position, using the letter G, of Gacrux. *[1 mark]*

3h. Discuss, with reference to its change in mass, the evolution of star P from the main sequence until its final stable phase. *[3 marks]*

Data from distant galaxies are shown on the graph.



4a. Estimate, using the data, the age of the universe. Give your answer in seconds. *[3 marks]*

4b. Identify the assumption that you made in your answer to (a). *[1 mark]*

4c. On the graph, one galaxy is labelled A. Determine the size of the universe, relative to its present size, when light from the galaxy labelled A was emitted. *[3 marks]*

Sirius is a binary star. It is composed of two stars, Sirius A and Sirius B. Sirius A is a main sequence star.

5a. State what is meant by a binary star. *[1 mark]*

5b. The peak spectral line of Sirius B has a measured wavelength of 115 nm. Show that the surface temperature of Sirius B is about 25 000 K. *[1 mark]*

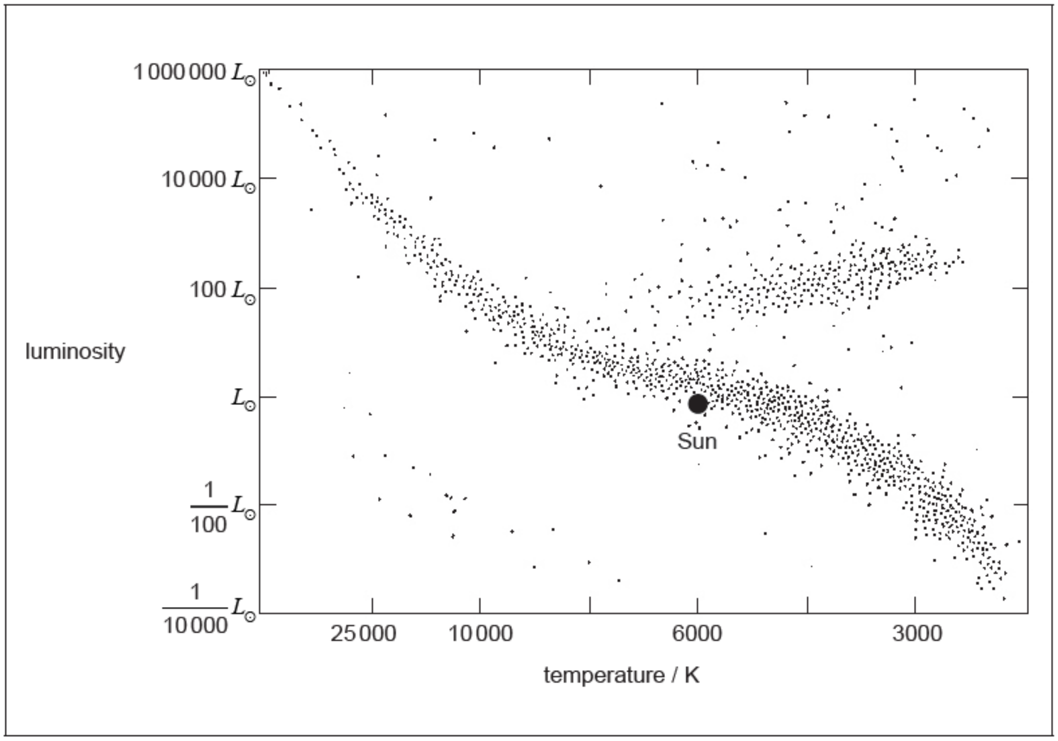
5c. The mass of Sirius B is about the same mass as the Sun. The luminosity of Sirius B is 2.5 % of the luminosity of the Sun. Show, with a calculation, that Sirius B is **not** a main sequence star. *[2 marks]*

The Sun's surface temperature is about 5800 K.

5d. Determine the radius of Sirius B in terms of the radius of the Sun. *[2 marks]*

5e. Identify the star type of Sirius B. *[1 mark]*

The image shows a Hertzsprung–Russell (HR) diagram.



The mass of Sirius A is twice the mass of the Sun. Using the Hertzsprung–Russell (HR) diagram,

5f. draw the approximate positions of Sirius A, labelled A and Sirius B, labelled B. *[1 mark]*

5g. sketch the expected evolutionary path for Sirius A. *[1 mark]*

The collision of two galaxies is being studied. The wavelength of a particular spectral line from the galaxy measured from Earth is 116.04 nm. The spectral line when measured from a source on Earth is 115.00 nm.

6a. Outline **one** reason for the difference in wavelength. *[1 mark]*

6b. Determine the velocity of the galaxy relative to Earth. *[2 marks]*

7a. State **two** characteristics of the cosmic microwave background (CMB) radiation. *[2 marks]*

7b. The present temperature of the CMB is 2.8 K. Calculate the peak wavelength of the CMB. *[1 mark]*

7c. Describe how the CMB provides evidence for the Hot Big Bang model of the universe. *[2 marks]*

A spectral line in the light received from a distant galaxy shows a redshift of $z = 0.16$.

7d. Determine the distance to this galaxy using a value for the Hubble constant of $H_0 = 68$ km s^{-1} Mpc^{-1}. *[2 marks]*

7e. Estimate the size of the Universe relative to its present size when the light was emitted by the galaxy in (c). *[2 marks]*

Theta 1 Orionis is a main sequence star. The following data for Theta 1 Orionis are available.

Luminosity	$L = 4 \times 10^5 L_\odot$
Radius	$R = 13 R_\odot$
Apparent brightness	$b = 4 \times 10^{-11} b_\odot$

where $L_\odot$, $R_\odot$ and $b_\odot$ are the luminosity, radius and apparent brightness of the Sun.

8a. State what is meant by a main sequence star. *[1 mark]*

8b. Show that the mass of Theta 1 Orionis is about 40 solar masses. *[1 mark]*

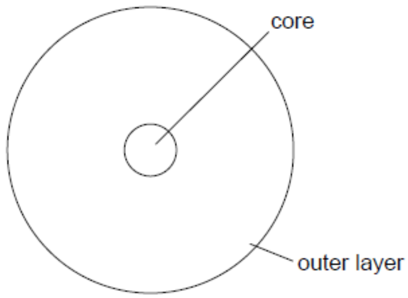
8c. The surface temperature of the Sun is about 6000 K. Estimate the surface temperature of Theta 1 Orionis. *[2 marks]*

8d. Determine the distance of Theta 1 Orionis in AU. *[2 marks]*

8e. Discuss how Theta 1 Orionis does not collapse under its own weight. *[2 marks]*

8f. The Sun and Theta 1 Orionis will eventually leave the main sequence. Compare and contrast the different stages in the evolution of the two stars. *[3 marks]*

The diagram shows the structure of a typical main sequence star.

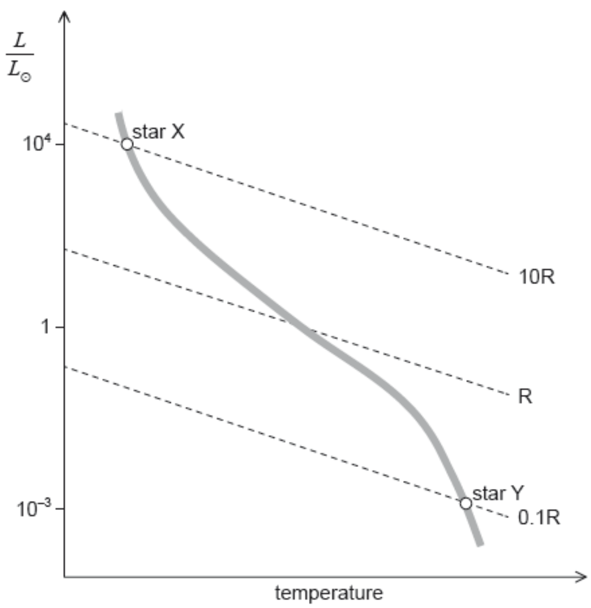


9a. State the most abundant element in the core and the most abundant element in the outer layer. *[2 marks]*

core: . . . .

outer layer: . . . .

9b. The Hertzsprung–Russell (HR) diagram shows two main sequence stars X and Y and includes lines of constant radius. *R* is the radius of the Sun. *[3 marks]*



Using the mass–luminosity relation and information from the graph, determine the ratio $\frac{\text{density of star X}}{\text{density of star Y}}$.

Star X is likely to evolve into a neutron star.

9c. On the HR diagram in (b), draw a line to indicate the evolutionary path of star X. *[1 mark]*

9d. Outline why the neutron star that is left after the supernova stage does not collapse under the action of gravitation. *[1 mark]*

9e. The radius of a typical neutron star is 20 km and its surface temperature is 10^6 K. Determine the luminosity of this neutron star. *[2 marks]*

9f. Determine the region of the electromagnetic spectrum in which the neutron star in (c)(iii) emits most of its energy. *[2 marks]*

10a. Describe what is meant by the Big Bang model of the universe. *[2 marks]*

10b. State **two** features of the cosmic microwave background (CMB) radiation which are consistent with the Big Bang model. *[2 marks]*

A particular emission line in a distant galaxy shows a redshift $z = 0.084$.

The Hubble constant is $H_0 = 68 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

10c. Determine the distance to the galaxy in Mpc. *[2 marks]*

10d. Describe how type Ia supernovae could be used to measure the distance to this galaxy. *[3 marks]*

Alpha Centauri A and B is a binary star system in the main sequence.

	Alpha Centauri A	**Alpha Centauri B**
Luminosity	$1.5L_{\odot}$	$0.5L_{\odot}$
Surface temperature / K	5800	5300

11a. State what is meant by a binary star system. *[1 mark]*

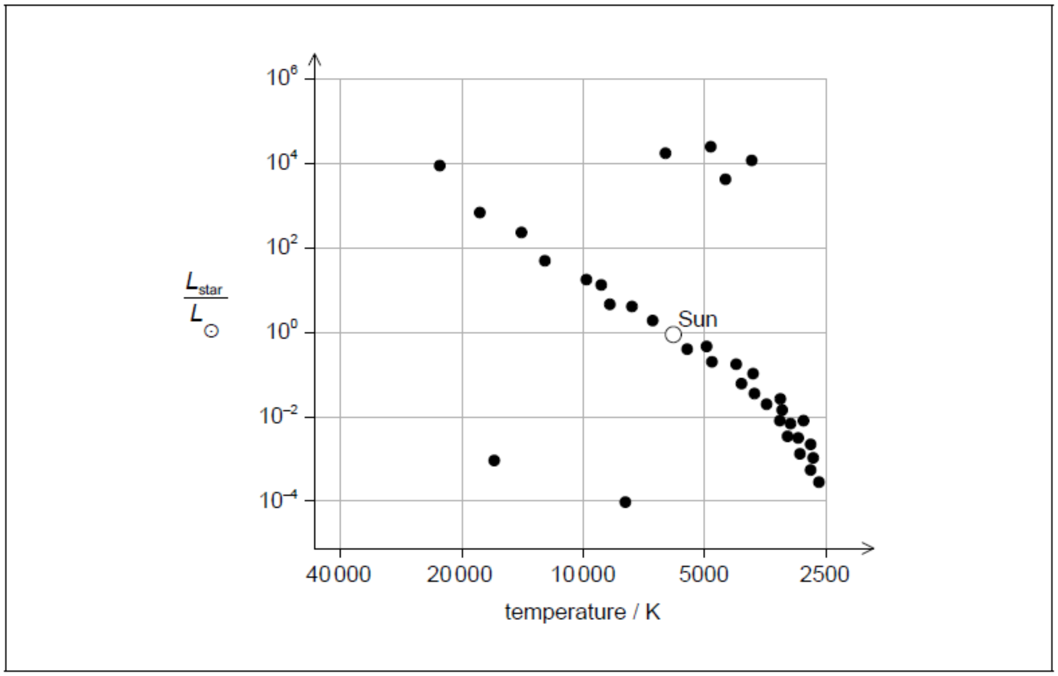
11b. (i) Calculate $\frac{b_A}{b_B} = \frac{\text{apparent brightness of Alpha Centauri A}}{\text{apparent brightness of Alpha Centauri B}}$. *[4 marks]*

(ii) The luminosity of the Sun is 3.8×10^{26} W. Calculate the radius of Alpha Centauri A.

11c. Show, without calculation, that the radius of Alpha Centauri B is smaller than the radius of Alpha Centauri A. *[2 marks]*

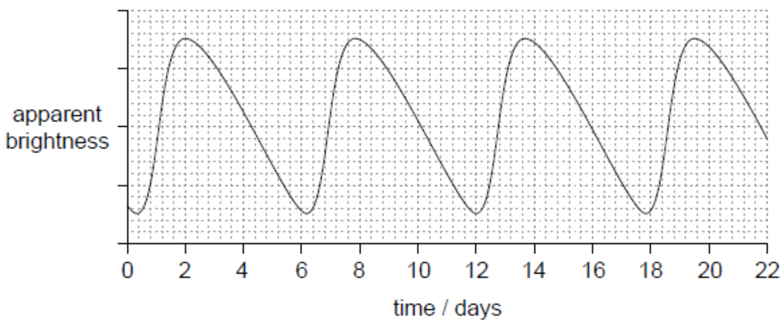
11d. Alpha Centauri A is in equilibrium at constant radius. Explain how this equilibrium is maintained. *[3 marks]*

11e. A standard Hertzsprung–Russell (HR) diagram is shown. *[2 marks]*

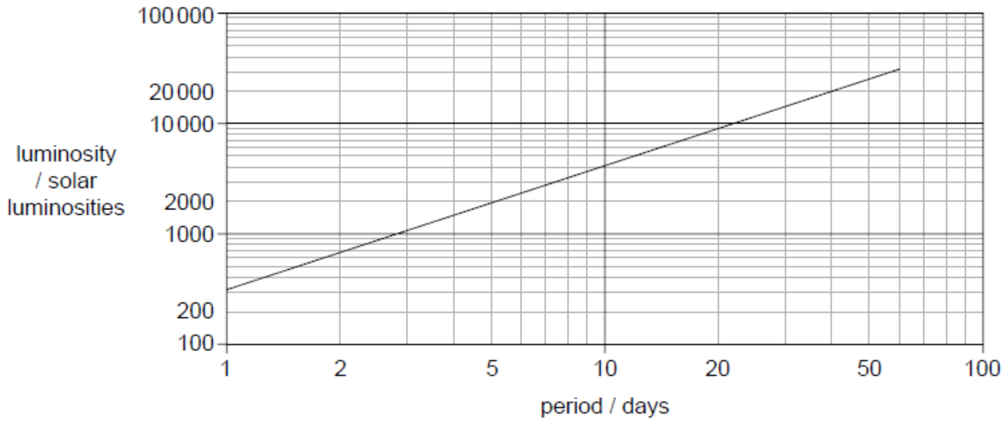


Using the HR diagram, draw the present position of Alpha Centauri A and its expected evolutionary path.

The first graph shows the variation of apparent brightness of a Cepheid star with time.



The second graph shows the average luminosity with period for Cepheid stars.



12a. Determine the distance from Earth to the Cepheid star in parsecs. The luminosity of the Sun is 3.8×10^{26} W. The average apparent brightness of the Cepheid star is 1.1×10^{-9} W m^{-2}. *[3 marks]*

12b. Explain why Cephids are used as standard candles. *[2 marks]*

The peak wavelength of the cosmic microwave background (CMB) radiation spectrum corresponds to a temperature of 2.76 K.

13a. Identify **two** other characteristics of the CMB radiation that are predicted from the Hot Big Bang theory. *[2 marks]*

13b. A spectral line in the hydrogen spectrum measured in the laboratory today has a wavelength of 21cm. Since the emission of the CMB radiation, the cosmic scale factor has changed by a factor of 1100. Determine the wavelength of the 21cm spectral line in the CMB radiation when it is observed today. *[1 mark]*

Aldebaran is a red giant star with a peak wavelength of 740 nm and a mass of 1.7 solar masses.

14a. Show that the surface temperature of Aldebaran is about 4000 K. *[2 marks]*

14b. The radius of Aldebaran is 3.1×10^{10} m. Determine the luminosity of Aldebaran. *[2 marks]*

14c. Outline how the light from Aldebaran gives evidence of its composition. *[2 marks]*

14d. Identify the element that is fusing in Aldebaran's core at this stage in its evolution. *[1 mark]*

14e. Predict the likely future evolution of Aldebaran. *[3 marks]*

15a. Light reaching Earth from quasar 3C273 has z=0.16. *[4 marks]*

(i) Outline what is meant by z.

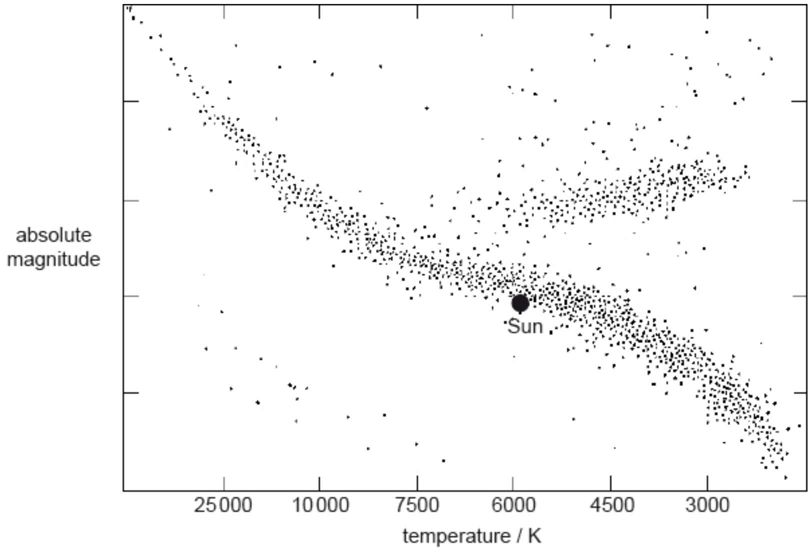
(ii) Calculate the ratio of the size of the universe when the light was emitted by the quasar to the present size of the universe.

(iii) Calculate the distance of 3C273 from Earth using H_0=68kms^{-1}Mpc^{-1}.

15b. Explain how cosmic microwave background (CMB) radiation provides support for the Hot Big Bang model. *[2 marks]*

This question is about the Hertzsprung–Russell (HR) diagram and the Sun.

A Hertzsprung–Russell (HR) diagram is shown.



16a. The following data are given for the Sun and a star Vega. *[3 marks]*

Luminosity of the Sun $= 3.85 \times 10^{26}\ \mathrm{W}$

Luminosity of Vega $= 1.54 \times 10^{28}\ \mathrm{W}$

Surface temperature of the Sun $= 5800\ \mathrm{K}$

Surface temperature of Vega $= 9600\ \mathrm{K}$

Determine, using the data, the radius of Vega in terms of solar radii.

16b. Outline how observers on Earth can determine experimentally the temperature of a distant star. *[3 marks]*

This question is about cosmic microwave background (CMB) radiation.

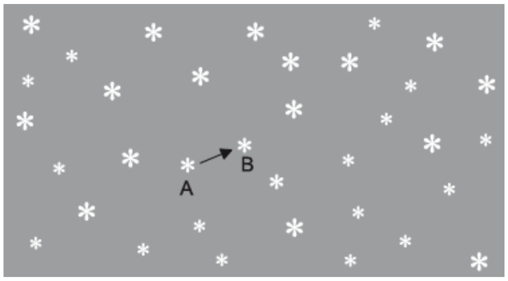
One of Newton's assumptions was that the universe is static. The peak intensity of the cosmic microwave background (CMB) radiation has a wavelength of 1.06 mm.

17a. Show that this corresponds to a temperature around 3 K. *[2 marks]*

17b. Suggest how the discovery of the CMB in the microwave region contradicts Newton's assumption of the static universe. *[2 marks]*

This question is about determining the distance to a nearby star.

Two photographs of the night sky are taken, one six months after the other. When the photographs are compared, one star appears to have shifted from position A to position B, relative to the other stars.



18. Discuss whether Hubble's Law can be used to determine reliably the distance from Earth to this star. *[2 marks]*

This question is about cosmic microwave background (CMB) radiation.

A line in the hydrogen spectrum is measured in the laboratory to have a wavelength of 656 nm. The same line from a distant galaxy is measured to have a wavelength of 730 nm. Assuming that the Hubble constant H_0 is $69.3\ \mathrm{km\,s^{-1}Mpc^{-1}}$,

19a. calculate the distance of this galaxy from Earth. *[2 marks]*

19b. discuss why different measurements of the Hubble constant do not agree with each other. *[1 mark]*

This question is about a particular star called Barnard's star.

The peak wavelength in the spectrum of Barnard's star is 940 nm. The following data are available.

$$\frac{\text{apparent brightness of Barnard's star}}{\text{apparent brightness of the Sun}} = 2.5 \times 10^{-14}$$

$$\frac{\text{luminosity of Barnard's star}}{\text{luminosity of the Sun}} = 3.8 \times 10^{-3}$$

20a. (i) Show that the surface temperature of Barnard's star is about 3000 K. *[4 marks]*

(ii) Suggest why Barnard's star is not likely to be either a white dwarf or a red giant.

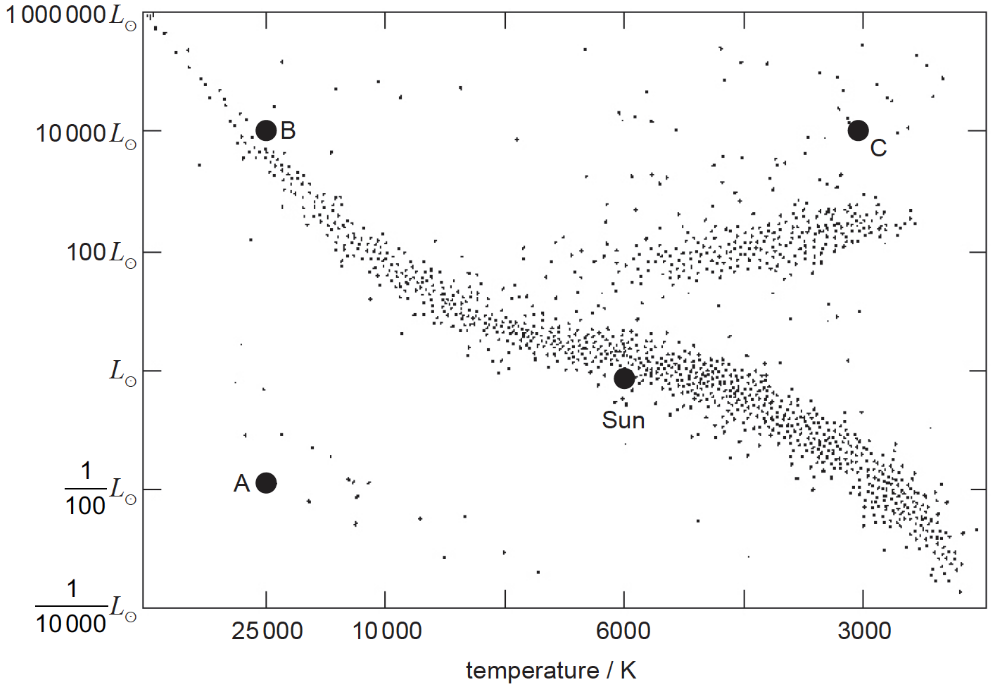
20b. (i) Determine, in astronomical units (AU), the distance between Earth and Barnard's star. *[8 marks]*

(ii) Calculate the parallax angle for Barnard's star as observed from Earth.

(iii) Outline how the parallax angle is measured.

This question is about stars.

The Hertzsprung–Russell (HR) diagram shows the position of the Sun and three stars labelled A, B and C.



21a. State the star type for A, B and C. *[3 marks]*

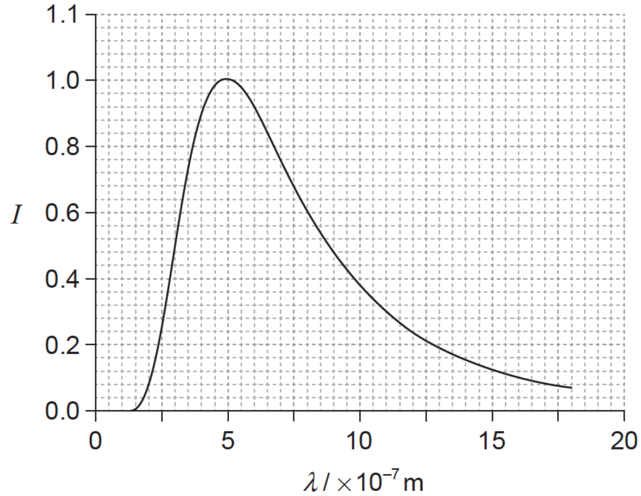
21b. The apparent brightness of C is 3.8×10^{-10} W m^{-2}. The luminosity of the Sun is 3.9×10^{26} W. *[4 marks]*

(i) State what is meant by apparent brightness and luminosity.

Apparent brightness:
Luminosity:

(ii) Determine the distance of C from Earth.

21c. The graph shows the variation with wavelength λ of the intensity I of the radiation emitted by 1.0m^2 of the surface of the Sun. The curve of the graph has been adjusted so that the maximum intensity is 1. *[2 marks]*



On the grid, draw a corresponding graph for star C. Your curve should have a maximum intensity of 1.

This question is about the expanding universe.

Since 1929 it has been thought that the universe is expanding.

22a. State what is meant by the expansion of the universe. *[1 mark]*

22b. Red-shift of light from distant galaxies provides evidence for an expanding universe. *[4 marks]*

(i) State **one** other piece of evidence in support of an expanding universe.

(ii) Explain how your answer in (b)(i) is evidence for the Big Bang model of the universe.

This question is about the mass–luminosity relation.

Star X is 1.5×10^5 more luminous than the Sun and has a mass 30 times that of the Sun.

23a. Identify whether star X is on the main sequence. Assume that $n = 3.5$ in the mass–luminosity relation. *[2 marks]*

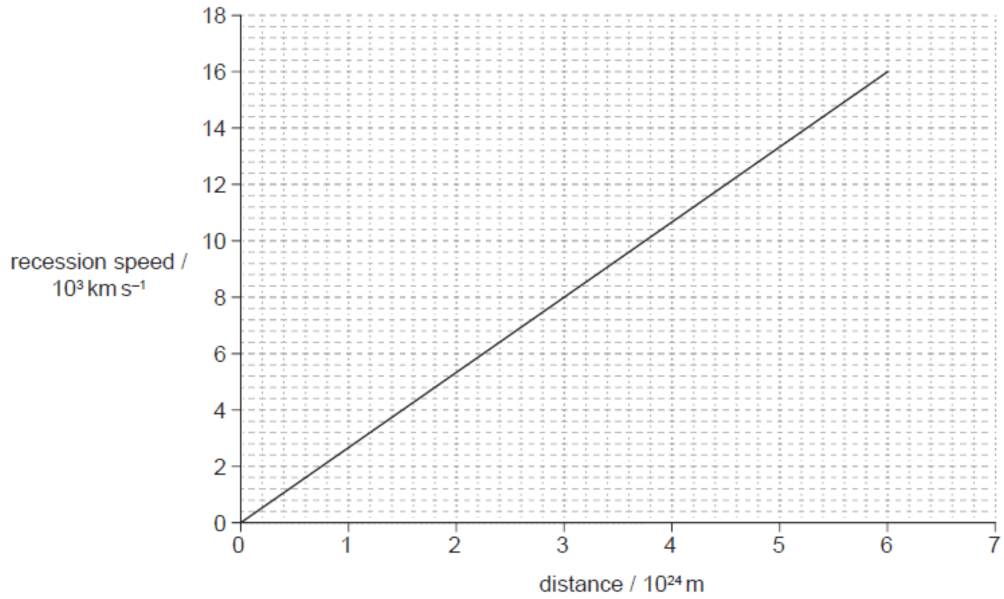
23b. (i) State the evolution of star X. *[3 marks]*

(ii) Explain the eventual fate of star X.

This question is about Hubble’s law.

24a. The light from distant galaxies is red-shifted. Explain how this red-shift arises. *[3 marks]*

24b. The graph shows the variation of recession speed with distance from Earth for some galactic clusters. *[4 marks]*



(i) Calculate, in s^{-1}, the Hubble constant..

(ii) Estimate, in s, the age of the universe.

(iii) State the assumption that you made in your estimate in (b)(ii).

This question is about stellar evolution.

25a. The mass of a main sequence star is two solar masses. Estimate, in terms of the solar luminosity, the range of possible values for the luminosity of this star. *[2 marks]*

25b. The star in (a) will eventually leave the main sequence. *[3 marks]*

State

(i) the condition that must be satisfied for this star to eventually become a white dwarf.

(ii) the source of the energy that the white dwarf star radiates into space.

(iii) **one** likely element, other than hydrogen and helium, that may be found in a white dwarf.

25c. Explain why a white dwarf maintains a constant radius. *[2 marks]*

This question is about Hubble's law.

26a. A galaxy a distance *d* away emits light of wavelength λ. Show that the shift in wavelength $\Delta\lambda$, as measured on Earth, is given by *[1 mark]*

$$\Delta\lambda = \frac{H_0 d\lambda}{c}$$

where H_0 is the Hubble constant.

26b. Light of wavelength 620 nm is emitted from a distant galaxy. The shift in wavelength measured on Earth is 35 nm. Determine the distance to the galaxy using a Hubble constant of 68 km $s^{-1}Mpc^{-1}$. *[1 mark]*

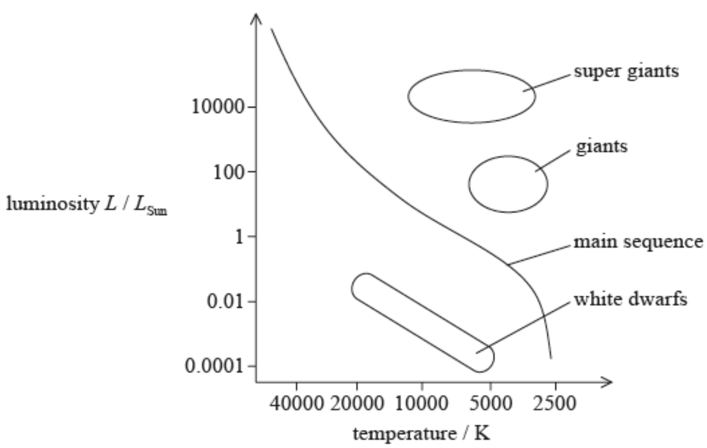
This question is about cosmology.

Newton assumed that the universe was infinite, uniform and static. The Big Bang model suggests space and time originated at one point around 14 billion years ago. At this time the temperature was very high.

27. In 1965, Penzias and Wilson discovered cosmic radiation with a wavelength that corresponded to a temperature of around 3 K. Outline how cosmic radiation in the microwave region is consistent with the Big Bang model. *[2 marks]*

This question is about the Hertzsprung–Russell (HR) diagram and stellar evolution.

The star Phi-1 Orionis is a large star on the main sequence with a mass of approximately 18 solar masses.



28a. Calculate the luminosity of Phi-1 Orionis in terms of the luminosity of the Sun. Assume that $n = 3.5$ in the mass–luminosity relation. *[2 marks]*

28b. The Sun is expected to have a lifespan of around 10^{10} years. With reference to the equilibrium between radiation pressure and gravitational pressure, discuss why Phi-1 Orionis will use up its hydrogen at a faster rate than the Sun. *[2 marks]*

28c. Using the HR diagram on page 6, draw the evolutionary path of Phi-1 Orionis as it leaves the main sequence. *[1 mark]*

28d. Outline, with reference to the Oppenheimer–Volkoff limit, the fate of Phi-1 Orionis. *[1 mark]*

This question is about the Hubble constant.

A recent estimate for the value of the Hubble constant is $70\ \mathrm{km^{-1}Mpc^{-1}}$.

29a. Estimate, in seconds, the age of the universe. *[2 marks]*

29b. The wavelength of the lines in the absorption spectrum of hydrogen is 656.3 nm when measured on Earth. Analysis of light from a distant galaxy shows that the same line has a wavelength of 725.6 nm. Determine the recessional velocity of the distant galaxy. *[2 marks]*

This question is about stellar evolution.

30a. Achernar is a main sequence star with a mass that is eight times the mass of the Sun. Deduce that Achernar has a greater temperature than the Sun. *[2 marks]*

30b. Outline why Achernar will spend less time on the main sequence than the Sun. *[2 marks]*

Achernar may evolve to become a neutron star.

30c. (i) State the condition relating to mass that must be satisfied for Achernar to become a neutron star. *[3 marks]*

(ii) Some neutron stars rotate about their axes and have strong magnetic fields. State how these stars may be detected.