1)

(a) State the *cosmological principle*.

....

....

....

.... **[2]**

(b) State some of the properties of the microwave background radiation observed from the Earth. Discuss how the background microwave radiation is linked to the big bang model of the universe.

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.... **[3]**

2) Please note, Olbers paradox is not in the current OCR A specification. So you can skip parts a and b of this question.

(a) State Olbers' paradox and the two assumptions made about the Universe.

....

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.... **[3]**

(b) State Hubble's law and explain how it resolves Olbers' paradox.

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.... **[2]**

(c) A galaxy at a distance of 1.4×10^{25} m is observed to be receding from the Earth at a velocity of 3.4×10^{7} m s^{-1}.

(i) Calculate the Hubble constant H_0 based on this data.

H_0 = ... unit .... **[3]**

(ii) Estimate

1 the age in years of the Universe

1 year = 3.2×10^{7} s

age = ...years **[2]**

2 the maximum distance in parsec (pc) we can observe from the Earth.

1 pc = 3.1×10^{16} m

distance = ... pc **[2]**

[Total: 12]

3)

(a) Explain what is meant by a *white dwarf* when describing the evolution of a star.

....

....

.... **[1]**

(b) Antares is a red giant and one of the brightest stars in the night sky. The parallax angle for this star is 0.0059 arc seconds.

Calculate its distance in light years from us.
1 pc = 3.26 ly

distance = ... ly **[2]**

(c) Sirius-B is a white dwarf. In comparison with Sirius-B, Antares has 12 times greater mass and has 1.1×10^5 times greater radius. The surface temperatures of Sirius-B and Antares are 25000 K and 4300 K respectively.

The intensity I of electromagnetic radiation emitted from the surface of a star is related to its temperature T in kelvin as follows:

$$I \propto T^4.$$

(i) Explain what is meant by *intensity*.

....

.... **[1]**

(ii) Calculate the ratio

1 $\dfrac{\text{mean density of Antares}}{\text{mean density of Sirius-B}}$

ratio = ... **[2]**

2 $\dfrac{\text{total power emitted from Antares}}{\text{total power emitted from Sirius-B}}$.

ratio = ... **[3]**

4)

(a) State Hubble's law.

....

....

.... **[1]**

(b) The redshift of a specific spectral line in the spectrum of a galaxy can be used to determine its recession velocity v. The fractional change z in the wavelength of a spectral line is given by the equation

$$z = \frac{v}{c}$$

where c is the speed of light in a vacuum.

The table of Fig. 11.1 shows data for some of our closest galaxies. The distance of the galaxy from the Earth is d.

Galaxy	z / 10^{-3}	v / 10^{3} m s^{-1}	d / 10^{23} m
A	1.12	336	1.50
B	1.61	483	2.14
C	1.85	555	2.46
D	2.26	678	3.00
Messier 109	3.38		

Fig. 11.1

(i) Complete the table by determining v and d for the galaxy Messier 109. **[2]**

(ii) Fig. 11.2 shows the data for the first four galaxies plotted on a v against d graph.

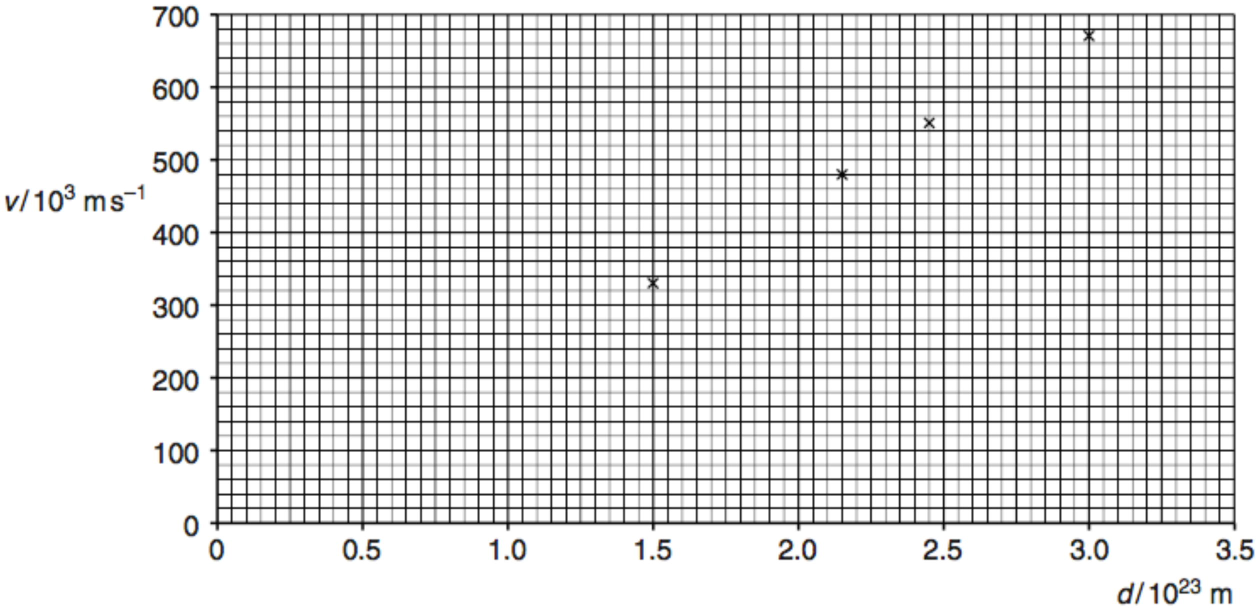

Fig. 11.2

Use Fig. 11.2 to determine the age of the Universe in years.
$1\,y = 3.16 \times 10^7\,s$

age = ... years **[3]**

(c) One piece of observational evidence for the big bang is that galaxies are receding from each other.
Explain what is meant by the big bang and suggest **two** other observations that support the big bang model of the Universe.

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.... **[3]**

5)

Sirius A and B are binary stars in our galaxy at a distance of 8.6 ly from the Sun. Sirius B is a white dwarf of diameter 12 km and mass 2.0×10^{30} kg.

(a) Calculate the density of Sirius B.

density = ... unit .... **[3]**

(b) The mass of the Sun is the same as Sirius B. The Sun has a diameter of 1.4×10^{9} m.

Calculate the ratio

$$\frac{\text{gravitational field strength on the surface of Sirius B}}{\text{gravitational field strength on the surface of the Sun}}.$$

ratio = ... **[2]**

(c) Calculate the parallax angle in arc seconds for Sirius B.

$1\,\text{pc} = 3.1 \times 10^{16}\,\text{m}$

parallax angle = ... arc seconds **[2]**

(d) Sirius A is moving towards the Earth at a relative velocity of $7600\,m\,s^{-1}$. Calculate the percentage change in the wavelength of a spectral line observed from this star compared with an identical spectral line observed in the laboratory.

percentage change = ... % **[2]**

(e) A student suggests that the distance of Sirius A can be calculated using Hubble's law and the speed given in **(d)**. Discuss whether this suggestion is correct or incorrect.

....

....

....

.... **[1]**

[Total: 10]

6)

(a) Calculate the distance of 1 light-year (ly) in metres.

distance = ... m **[1]**

(b) Fig. 10.1 shows an incomplete diagram drawn by a student to show what is meant by a distance of 1 parsec (pc).

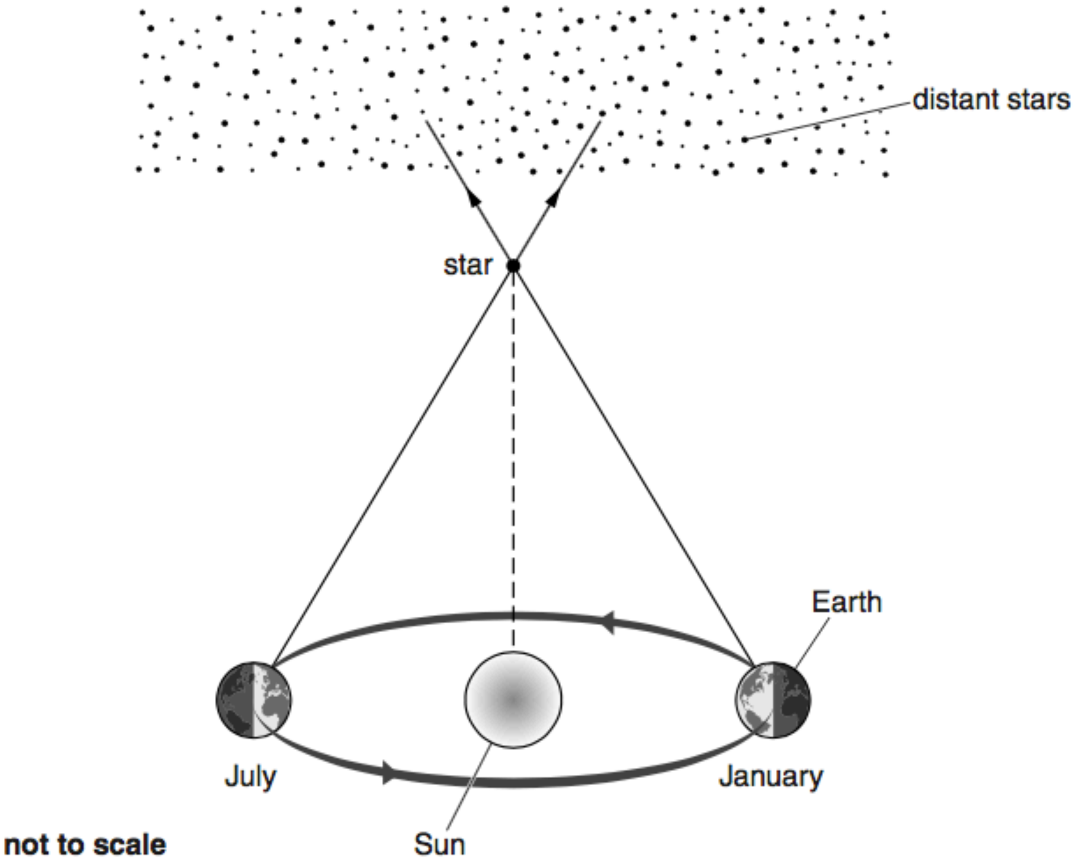

Fig. 10.1

Complete Fig. 10.1 by showing the distances of 1 pc and 1 AU, and the parallax angle of 1 second of arc (1″). **[1]**

(c) A recent supernova, SN2011fe, in the Pinwheel galaxy, M101, released 10^{44} J of energy. The supernova is 2.1×10^7 ly away.

(i) Calculate the distance of this supernova in pc.

$1 \text{ pc} = 3.1 \times 10^{16}$ m

distance = ... pc **[2]**

(ii) Our Sun radiates energy at a rate of 4×10^{26} W. Estimate the time in years that it would take the Sun to release the same energy as the supernova SN2011fe.

time = ... y **[2]**

(d) One of the possible remnants of a supernova event is a black hole. State **two** properties of a black hole.

....

....

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.... **[2]**

[Total: 8]

7)

(a) One estimate of the age of the universe is 13.7×10^9 years.

(i) Calculate the Hubble constant in $km\,s^{-1}\,Mpc^{-1}$ using this age.

1 pc = 3.09×10^{16} m

Hubble constant = ... $km\,s^{-1}\,Mpc^{-1}$ **[3]**

(ii) The wavelength of the hydrogen-alpha spectral line in the laboratory is 656 nm. Calculate the observed wavelength of this spectral line in the spectrum of the galaxy NGC 7469, which is 50.0 Mpc away from the Earth.

wavelength = ... nm **[4]**

(b) State what is meant by the big bang. Describe how it explains the origin of the microwave background radiation.

In your answer, you should make clear how the microwave background radiation supports the Cosmological Principle.

[5]

(c) Suggest how the microwave background radiation may evolve in the future.

....

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.... **[2]**

(d) Recent observations of very distant supernovae have shown that the expansion of the universe may be accelerating. It is suggested that this is caused by *dark energy* which has the mysterious property of exerting a repulsive force on the universe. The universe may therefore be *open* rather than *flat* or *closed*.

Fig. 11.1

Complete Fig. 11.1 by sketching a suitable graph to illustrate an open universe. **[1]**

[Total: 15]

Please note, open and closed universes are not mentioned in the current OCR A specification.
So you can skip part d of this question.

8)

(a) Define the *parsec*. Draw a diagram to illustrate your answer.

....

.... **[2]**

(b) The star Tau Ceti has a parallax of 0.275 seconds of arc.

Calculate the distance of Tau Ceti from Earth

(i) in parsec (pc)

distance = ... pc **[1]**

(ii) in light year (ly).

1 pc = 3.1×10^{16} m

distance = ... ly **[2]**

[Total: 5]

9)

(a) State Hubble's Law.

....

.... **[1]**

(b) The dark lines of the spectrum observed from a distant galaxy are red-shifted by 15% of their normal wavelengths.

The Hubble constant is estimated to be 65 $km\,s^{-1}\,Mpc^{-1}$. One parsec = 3.1×10^{16} m.

(i) Show that the speed of the galaxy is $4.5 \times 10^7\,m\,s^{-1}$.

[1]

(ii) Estimate the distance of the galaxy from the Earth.

distance = ... m **[2]**

(iii) Estimate the age of the universe in years.

1 year = 3.2×10^7 s

age = ... y **[2]**

(c) The age of the universe is calculated from the time of the big bang. Describe **two** observations that directly support the idea of the big bang.

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.... **[2]**

[Total: 8]

10)

(a) (i) Describe the formation of a star such as our Sun and its most probable evolution.

In your answer you should make clear how the steps in the process are sequenced.

[6]

(ii) Describe the probable evolution of a star that is much more massive than our Sun.

[2]

(b) The present mass of the Sun is 2.0×10^{30} kg. The Sun emits radiation at an average rate of 3.8×10^{26} J s^{-1}. Calculate the time in years for the mass of the Sun to decrease by one millionth of its present mass.

$1 \text{ y} = 3.2 \times 10^{7}$ s

time = ... y **[3]**

(c) The following nuclear equation summarises a typical fusion reaction cycle that occurs in the Sun.

$$4\,{}^{1}_{1}\text{H} \longrightarrow {}^{4}_{2}\text{He} + 2\,{}^{0}_{1}\text{e} + 2\nu$$

(i) Explain the process of nuclear fusion in the core of the Sun. In your explanation refer to the conditions necessary for fusion to occur.

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.... **[4]**

(ii) Name two forms of energy produced in thermonuclear reactions.

1. ....

2. .... **[2]**

(iii) The binding energy per nucleon of ${}^{1}_{1}\text{H}$ and ${}^{4}_{2}\text{He}$ are 0 and 7.2 MeV respectively. Calculate the energy produced in joules for the fusion reaction above.

energy = ... J **[2]**

[Total: 19]

11)

(a) Describe the formation of the Sun.

In your answer, you should make clear how the steps of the process are sequenced.

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.... **[5]**

(b) After the death of a low-mass star such as our Sun, the remnant core is a white dwarf.

State two properties of a white dwarf.

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.... **[2]**

(c) The ultimate fate of the universe depends on its density.

(i) State the fate of the universe if its density is equal to the critical density.

....

.... **[1]**

(ii) According to some cosmologists, the age of the universe is 4.4×10^{17} s (about 14 billion years). Show that according to this age, the critical density of the universe is about 10^{-26} kg m^{-3}.

[3]

(iii) Estimate the number of protons per cubic metre of space.

mass of proton = 1.7×10^{-27} kg

number = ... m^{-3} **[2]**

(d) The universe began from a big bang. At an early stage of the universe, the temperature was about 10^8 K. The expansion of the universe led to cooling. The present temperature of the universe is about 2.7 K. For a single **electron**, determine the ratio

$$\frac{\text{speed of electron at } 10^8\,\text{K}}{\text{speed of electron at } 2.7\,\text{K}}.$$

ratio = ... **[2]**

[Total: 15]

12)

(a) A star radiates energy produced from fusion reactions within its core. Explain what is meant by *fusion* and explain the conditions necessary for fusion to occur in the core of a star.

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.... **[4]**

(b) Describe and explain the evolution of a star much more massive than our Sun.

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.... **[3]**

[Total: 7]

13)

(a) In the universe there are about 10^{11} galaxies, each with about 10^{11} stars with each star having a mass of about 10^{30} kg. Estimate the attractive gravitational force between two galaxies separated by a distance of 4×10^{22} m.

force = ... N **[3]**

(b) Explain why the galaxies do not collapse on each other.

....

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.... **[1]**

(c) Describe qualitatively the evolution of the universe immediately after the big bang to the present day. You are not expected to state the times for the various stages of the evolution.

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.... **[6]**

(d) Fig. 10.1 shows some absorption spectral lines of the spectrum of calcium as observed from a source on the Earth and from a distant galaxy.

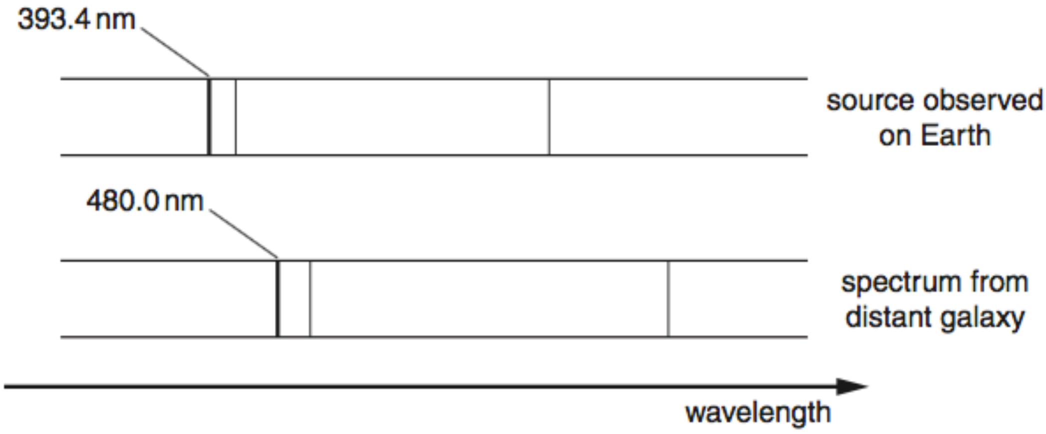

Fig. 10.1

(i) Describe an absorption spectrum.

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.... **[2]**

(ii) Use Fig. 10.1 to calculate the distance of the galaxy in Mpc. The Hubble constant has a value of 50 $km\,s^{-1}\,Mpc^{-1}$.

distance = ... Mpc **[3]**

[Total: 15]

14)

Please note, Critical density is not in the current OCR A specification. So you can skip this question.

(a) Explain what is meant by the *critical density* of the universe.

....

.... **[1]**

(b) Cosmologists have determined the Hubble constant to be 65 km s^{-1} Mpc^{-1}. Calculate the Hubble constant in s^{-1} and hence determine the critical density of the universe.

1 pc = 3.1×10^{16} m

Hubble constant = ... s^{-1}

critical density = ... kg m^{-3} **[3]**

(c) (i) Explain the terms *open*, *closed* and *flat* when describing the possible evolution of the universe. On Fig. 7.1 sketch and label graphs to illustrate your answer.

Fig. 7.1

open ....

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....

closed ....

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flat ....

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.... [3]

(ii) Suggest a reason why it is difficult to predict the future of the universe.

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.... [1]

Please note, open and closed universes are not mentioned in the current OCR A specification.
So you can skip part d of this question.

[Total: 8]

15)

Please note, Olbers paradox is not in the current OCR A specification. So you can skip part a of this question.

(a) Olbers' paradox is based on two assumptions about the nature of our Universe. State these two assumptions.

....

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.... **[2]**

(b) Fig. 2.1 shows how the recessional speed *v* of galaxies varies with their distance *d* from the Earth.

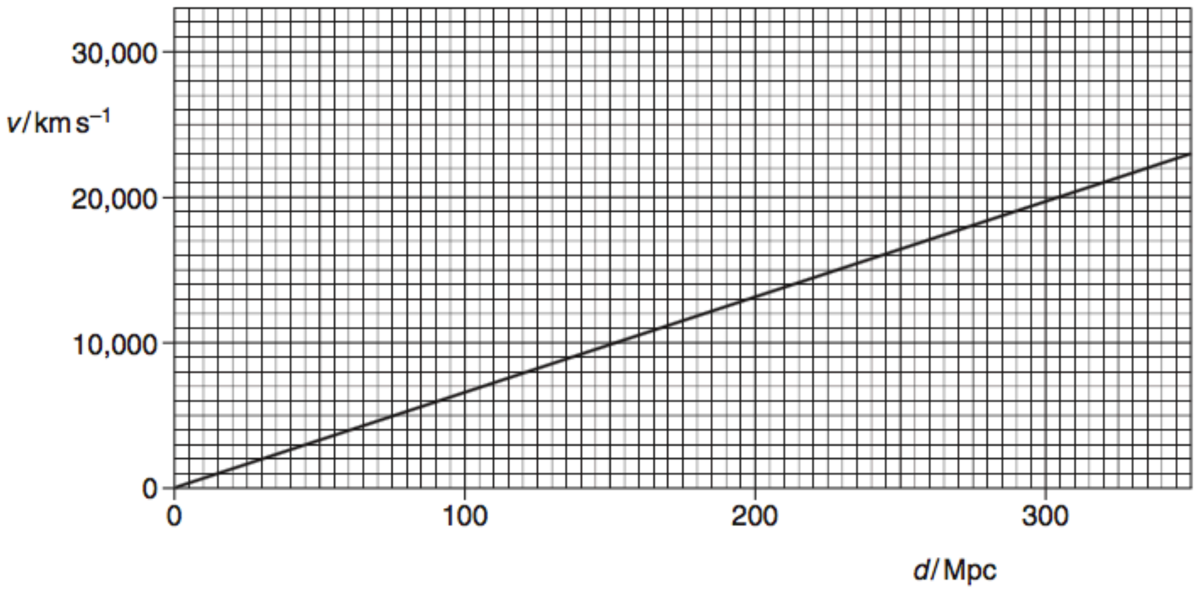

Fig. 2.1

(i) Use Fig. 2.1 to determine the Hubble constant.

Hubble constant = ... $km\,s^{-1}\,Mpc^{-1}$ **[2]**

(ii) Hence estimate the age of the Universe in years.

1 year = 3.2×10^7 s and 1 pc = 3.1×10^{16} m

age = ... y **[3]**

Please note, Critical density is not in the current OCR A specification. So you can skip part c of this question.

(c) **(i)** Calculate the critical density of the Universe using the Hubble constant determined in **(b)(i)**.

critical density = ... $kg\,m^{-3}$ **[2]**

(ii) Describe how the fate of the Universe depends on its average density.

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.... **[3]**

(d) Describe the evidence for the hot big bang model of the Universe.

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.... **[4]**

[Total: 16]

16)

(a) Describe briefly the sequence of events which occur in the formation of a star, such as our Sun, from interstellar dust and gas clouds.

In your answer, you should make clear how the steps in the process are sequenced.

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.... **[4]**

(b) Fig. 8.1 shows the evolution of a star similar to our Sun on a graph of intensity of emitted radiation against temperature.

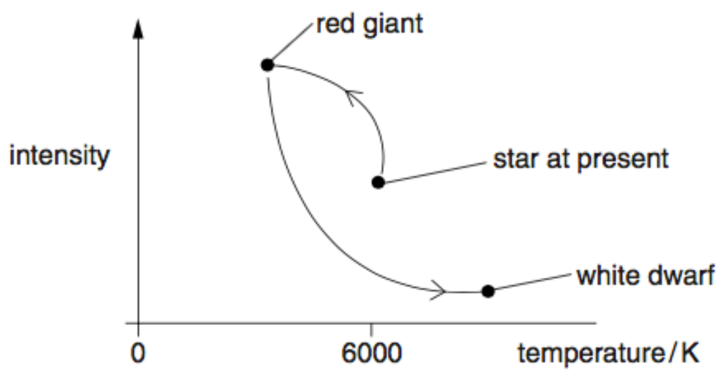

Fig. 8.1

(i) The final evolutionary stage of the star is a white dwarf. Describe some of the characteristics of a white dwarf.

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.... **[2]**

(ii) Explain why, in its evolution, the star is brightest when at its coolest.

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.... **[2]**

[Total: 8]