1 State and explain **two** differences between the evolution of high and low mass stars.

1. ....

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....

....

2. ....

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....

[4]

2 **(a)** State Hubble's law.

....

....[1]

(b) A line in the spectrum of calcium has a wavelength of 396.8 nm when measured from a stationary laboratory source. The same spectral line is observed in five galaxies, resulting in the data shown in Fig. 5.1.

galaxy	distance /Mpc	λ_{obs}/nm	recession velocity/km s^{-1}
A	25	398.2	1058
B	300	416.6	14970
C	430	427.2	22980
D	750	448.1	38790
E	1200	476.9	60560

Fig. 5.1

(i) Explain how the recession velocities have been calculated from the wavelengths.

....

....

....[2]

(ii) On Fig. 5.2, plot a graph of recession velocity against distance. [3]

(iii) Using your graph, show that the data are consistent with a value for the Hubble constant H_0 of approximately $50\,km\,s^{-1}\,Mpc^{-1}$.

[2]

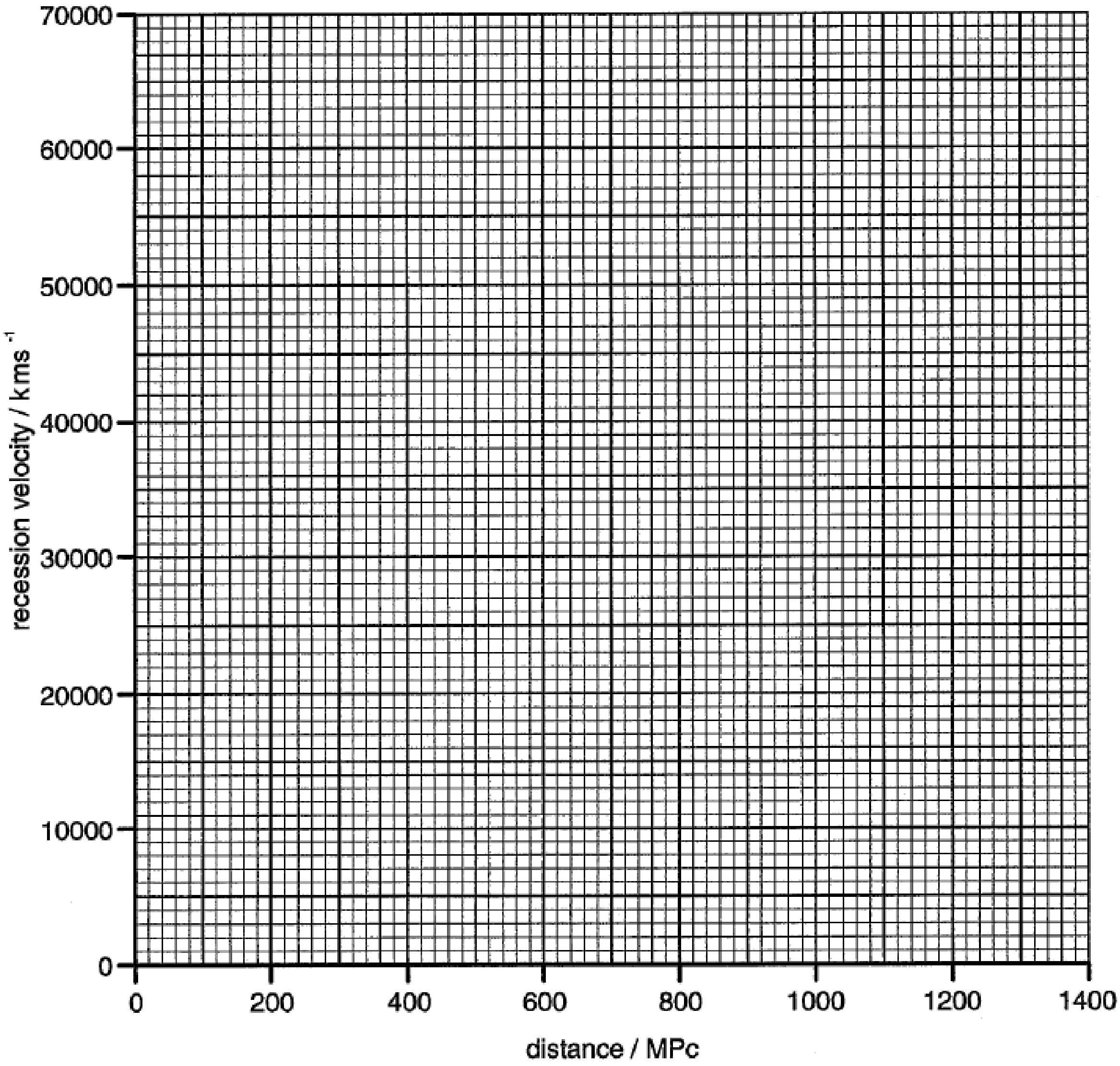

Fig. 5.2

[Total : 8]

3 The first stars were not formed until some time after the Big Bang.

(a) Outline how the first main sequence stars formed from clouds of gas.

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....[3]

(b) The first stars are believed to have consisted solely of hydrogen and helium.

(i) State the origin of the helium.

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(ii) State **one** major difference in chemical composition between the 'first' stars and the Sun.

....

....
[2]

[Total : 5]

4 The critical density of the Universe can be shown to be given by the equation

$$\rho_0 = \frac{3H_0^2}{8\pi G}.$$

(a) State **two** assumptions made in the derivation of this equation.

1. ....

....

2. ....

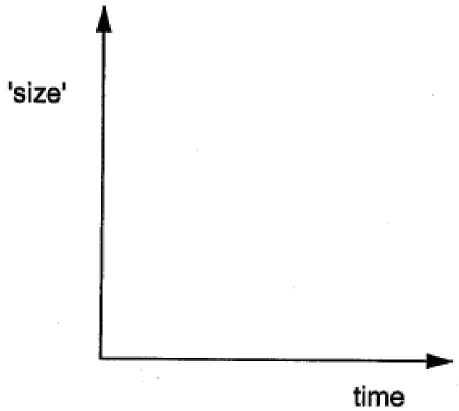
....
[2]

(b) Calculate the critical density of the Universe, giving your answer in hydrogen atoms per cubic metre. Hubble constant $H_0 = 1.6 \times 10^{-18}\,s^{-1}$, and the mass of a hydrogen atom = 1.7×10^{-27} kg.

Critical density = ... hydrogen atoms per cubic metre [4]

(c) Theory suggests that the Universe may have three possible fates, referred to as *open*, *flat* and *closed*. Describe each of these and illustrate the evolution of the Universe in each case by a suitable sketch graph.

1. Open



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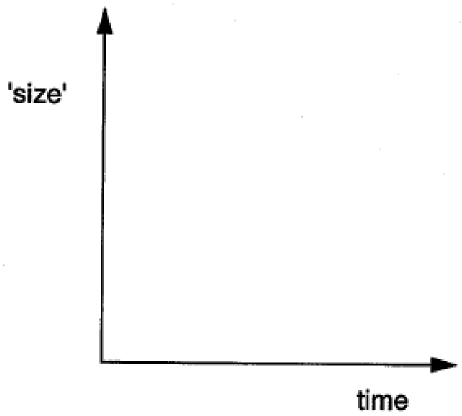
2. Flat



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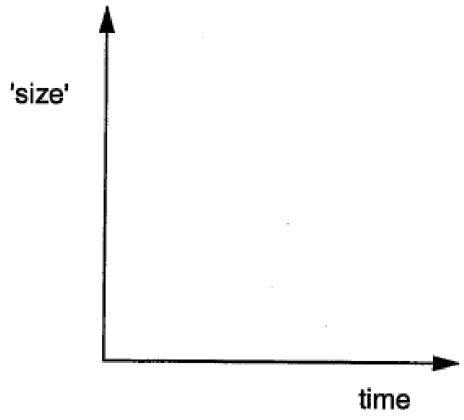
3. Closed



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[6]

[Total : 12]

5 The Sun produces its energy mainly by a series of nuclear fusion reactions in which hydrogen is converted to helium. For each 1.000 kg of hydrogen consumed in the fusion reactions, the rest mass of the products is only 0.993 kg. This change in mass is associated with the production of energy.

(a) Calculate the energy produced from 1.000 kg of hydrogen.

energy = ... J [4]

(b) The Sun's power output is 3.9×10^{26} W. Calculate the rate at which the Sun is using up its hydrogen.

rate of consumption of hydrogen = ... kg s^{-1} [2]

(c) The mass of the Sun is 2.0×10^{30} kg and it is expected to leave the Main Sequence when approximately 10% of its hydrogen has been used up.

(i) Estimate the Main Sequence lifetime of the Sun. Give a suitable unit for your answer.

lifetime = ...

(ii) State **one** assumption you have made in carrying out this calculation.

....

....
[4]

[Total : 10]

6

(a) State **three** properties of the cosmic microwave background radiation.

1. ....

2. ....

3. ....
[3]

(b) Describe how the microwave background radiation is thought to have arisen in standard Big Bang cosmology.

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....[5]

(c) The Cosmological Principle states that 'on a sufficiently large scale, the Universe is *homogeneous* and *isotropic*'.

(i) Explain the meaning of the terms *homogeneous* and *isotropic*.

homogeneous..

....

isotropic..

....
[2]

(ii) State how the microwave background radiation supports the Cosmological Principle.

....

....[1]

[Total : 11]

7 **(a)** Outline the assumptions and arguments leading to Olbers' paradox. Explain how it may be resolved in big-bang cosmology.

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....[6]

(b) A certain galaxy at a distance of 300 Mpc is observed to be receding from Earth at a velocity of 21 000 km s^{-1}.

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

H_0 = ... km s^{-1} Mpc^{-1} [1]

(ii) Estimate the age of the Universe using your answer to **(b)(i)**.

age = ... s [3]

(iii) Explain why the Hubble constant is not really a constant at all.

....

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....[2]

[Total: 12]

8

The Universe is observed to be expanding. If we project this expansion back into the past, we find that the Universe must have had zero size in the finite past, at the time of the big bang.

(a) Why is it very difficult to project the evolution of the Universe before 0.01 s after the big bang?

....

....[1]

(b) Theory predicts that exactly equal amounts of matter and antimatter would have been produced in the big bang, and yet the observable Universe appears to contain relatively little antimatter. Suggest what happened to all the antimatter in the very early moments after the big bang.

....

....

....[2]

(c) The Universe is observed to be filled with a highly isotropic blackbody background radiation. What does this tell us about conditions in the early Universe?

....

....

....[2]

[Total: 5]

9

(a)

The distances to nearby stars may be determined by *parallax*, and are often quoted in *parsecs*.

(i) Explain the meaning of the term *parallax*.

....

....[2]

(ii) Explain how the *parsec* is defined. A diagram may be helpful.

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....[2]

10

(a) State and explain the evidence in support of the big bang model of the Universe, including the microwave background radiation.

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....[4]

(b) There is some evidence from observations of extremely distant *supernovae* that the expansion of the Universe may be accelerating so that the Universe is *open*.

(i) Describe what happens in a *supernova*.

....

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....[2]

(ii) What is an *open Universe*?

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....

....[2]

(iii) What effect would such an accelerating expansion have on the value of the Hubble constant?

....

....**[1]**

[Total: 9]

11 **(a)** Explain how Olbers' paradox and the work of Hubble on the motions of galaxies provide evidence for a finite Universe.

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....[6]

(b) The Hubble constant H_o is given by the equation

$$H_o = \frac{v}{r}$$

where v is the speed of recession of a galaxy and r is the distance from the observer to the galaxy.

(i) Some observations indicate a value for the Hubble constant of $H_o = 70\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. Convert this value into s^{-1}.

H_o = ... s^{-1} [3]

(ii) Hence estimate the age of the Universe.

age = ... s [1]

(iii) Use your answer to **(ii)** to estimate the maximum observable size for the Universe.

size = ... m [2]

(c) State an assumption you have made in answering **(b)**.

....

....[1]

[Total: 13]

12 Explain what is meant by the term *white dwarf*.

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....[3]

13 **(a)** The hydrogen and helium atoms forming most of the visible matter in the Universe are believed to have been produced following the Big Bang. Discuss how this model explains the formation of these atoms.

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....[6]

(b) The future evolution of the Universe depends on the density parameter Ω, which is the ratio of the actual density of the Universe ρ to its critical value ρ_0,

$$\Omega = \frac{\rho}{\rho_0}.$$

Discuss how different values of Ω predict different possibilities for the future evolution of the Universe.

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....[6]

14

The cosmic microwave background radiation is evidence for the way in which the Universe began. State a feature of the intensity of this microwave background radiation.

.... [1]