15

(a) In 1929 Edwin Hubble showed that the Universe was expanding by studying the light from stars and galaxies. Explain how.

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(b) Suggest why many stars within our galaxy do not conform with Hubble's law.

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(c) Estimate the age of the Universe, giving your answer in seconds. Show your working and take the Hubble constant to be 75 km s^{-1} Mpc^{-1}.

age = ... s [3]

(d) Describe how the fate of the Universe depends upon its mean density and explain why this ultimate fate is not yet known.

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[Total: 15]

16

(a) Large distances in the Universe may be measured in parsecs. Explain what is meant by a *parsec*.

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17

(a) Explain how a main sequence star can develop into a supernova. Discuss what may remain after the explosion.

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(b) It is estimated that the Sun radiates energy at the rate of 3.8×10^{26} W and that a supernova explosion may produce 10^{44} J of energy.

(i) Calculate the rate at which mass is converted into energy within the Sun.

mass rate = ... $kg\,s^{-1}$ [2]

(ii) Calculate the time, in years, that it would take the Sun to produce the same amount of energy as that released in a supernova explosion. Assume 1 year to be 3.2×10^7 s.

time = ... y [2]

[Total: 10]

18

(a) What is the *Cosmological Principle*?

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..... [2]

(b) Describe the important properties of the cosmic microwave background radiation and how the standard model of the Universe explains these properties. Explain their significance as evidence for the past evolution of the Universe.

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(c) Why is our understanding of the very earliest moments of the Universe unreliable?

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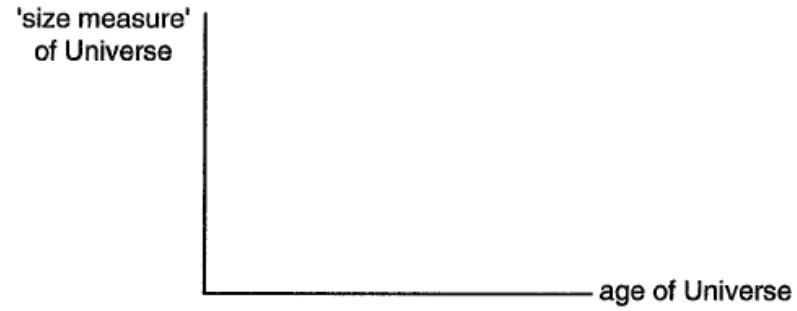
[Total: 9]

19

(a) The future of the Universe may be *open*, *closed* or *flat*. Explain the meaning of the terms in italics, using a graph to illustrate your answer.



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(b) The mean density of the Universe, ρ_0, is thought to be approximately 1×10^{-26} kg m^{-3}. Calculate a value for the Hubble constant H_0.

H_0 = ...s^{-1} [2]

[Total: 6]

20

(a) Some stages in the early evolution of the Universe are represented in Fig. 5.1.

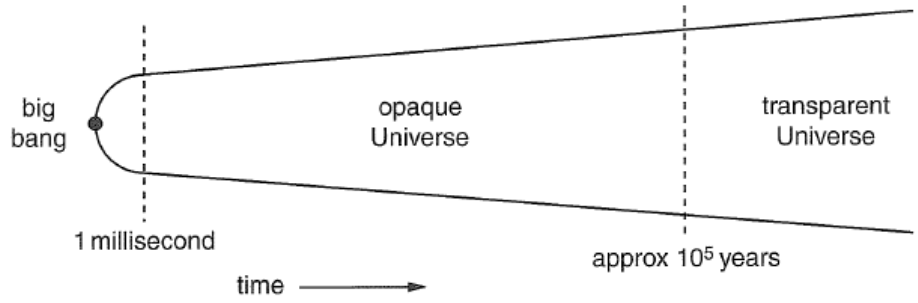

Fig. 5.1

(i) What limits our understanding of events in the first millisecond?

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..... [1]

(ii) State and explain how the temperature of the Universe has changed after the first millisecond.

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(b) Describe and explain **two** pieces of evidence which suggest that the Universe did in fact begin with a big bang.

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[Total: 11]

21 When a star ceases to be Main Sequence, it may evolve in several different ways. Explain the circumstances which will lead to the formation of a neutron star.

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22 **(a)** What is meant by the *cosmological principle*?

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(b) The ultimate fate of the Universe is not yet clear. Fig. 6.1 shows a graph where the size of the Universe is represented from the big bang **B** to the present day **P**. The graph has been extended into the future by the dotted line (– – – – –).

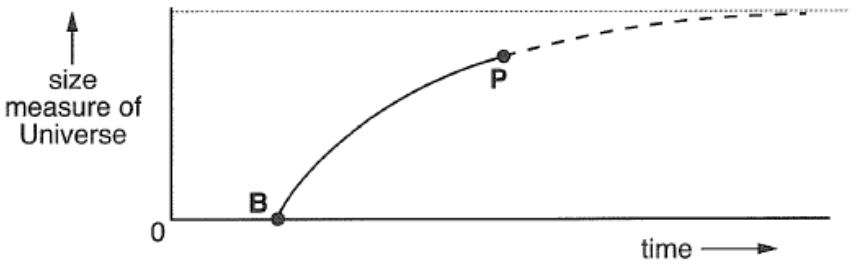

Fig. 6.1

(i) Calculate a value for the age of the Universe in years. Assume the Hubble constant to be $75\,km\,s^{-1}\,Mpc^{-1}$.

age = ... years [3]

(ii) Describe and explain what final fate for the Universe is represented in Fig. 6.1.

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..... [2]

(iii) The mass of the Universe may be significantly greater than that assumed in **(b)**. Taking this to be case, sketch a second graph on Fig. 6.1 using the same scales to show the future evolution of the Universe. [2]

(iv) Comment upon the implications of your graph for the future of the Universe.

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..... [1]

[Total: 10]

23 **(a)** What is meant by the *Doppler Effect*?

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24

(a) Outline the evolution of the Universe from the Big Bang to the formation of the first atoms.

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(b) State **one** feature of the cosmic microwave background radiation and explain how it provides evidence for the Big Bang theory.

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(c) **(i)** Show that the average energy of a photon of the cosmic microwave background radiation is 1.8×10^{-22} J. Assume an average wavelength of 1.1 mm.

[2]

(ii) Show that the rest mass energy of a proton or neutron is about 1.5×10^{-10} J.

Assume the mass of either particle to be 1.7×10^{-27} kg.

[2]

(iii) It is thought that at present there may be as many as 1000 million photons from the cosmic microwave background radiation for each proton or neutron in the Universe. Calculate the ratio

$$\frac{\text{rest mass energy of 1 proton or neutron}}{\text{energy of 1000 million photons}}.$$

ratio = ... [1]

(iv) Explain how the value of this ratio might have been different when the Universe was much younger. Assume that the number of protons and neutrons has remained constant during this time.

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..... [2]

[Total: 15]

25 **(a)** What is meant by *stellar parallax*?

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.....[2]

(b) The first recorded stellar parallax had a value of 0.314 arc seconds.

(i) Calculate the distance of the star from Earth, giving your answer in parsecs.

distance = ... pc [2]

(ii) What is this distance in metres?

distance = ... m [1]

(c) The distances d of some galaxies, together with their recessional velocities v are given in Fig. 3.1.

distance of galaxy d / 10^{24} m	velocity of galaxy v / 10^{7} m s^{-1}
5.3	1.1
6.6	1.4
7.3	1.5
10.7	2.2

Fig. 3.1

(i) Plot a graph of recessional velocity v against distance d on Fig. 3.2. [1]

(ii) Draw the best straight line through the points. [1]

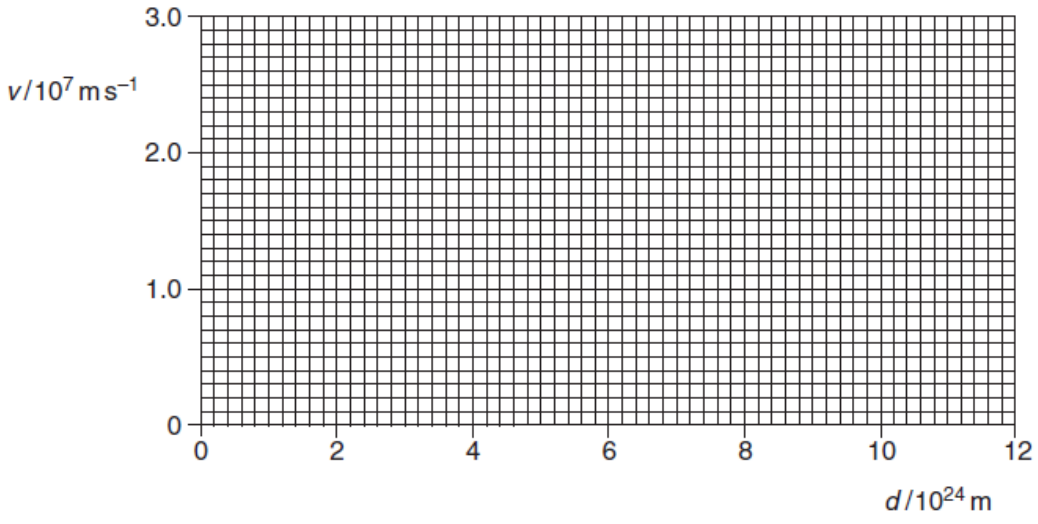

Fig. 3.2

(iii) The relationship between v and d is

$$v = kd$$

where k is a constant.
From your graph find, stating the unit in each case, the values of

1 k

k = ... unit ..... [2]

2 $\frac{1}{k}$

$\frac{1}{k}$ = ... unit ..... [1]

(iv) Explain the significance of your answers to **(iii)**.

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.....[2]

(d) Suggest why the method of stellar parallax was **not** used to obtain the distance data in Fig. 3.1.

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.....[2]

[Total: 14]

26

(a) The Universe is assumed to be *isotropic* and *homogenous*. Explain the meaning of these two terms.

isotropic .....

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homogenous .....

.....[2]

(b) One possible value for the critical density of the Universe is 3.3×10^{23} kg pc^{-3}.

(i) Assuming this density, what average volume of space would be required to contain a mass of 2×10^{30} kg, the mass of the Sun?

volume = ... pc^3 [2]

(ii) Explain how the Universe would evolve if measurements showed that the volume required to contain 1 solar mass was significantly greater than that found in **(i)**.

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[Total: 7]

27

(a) State and explain **two** pieces of evidence which suggest that the Universe began with a 'big bang'.

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