D_4D_5 *[107 marks]*

1a. Describe the formation of a type Ia supernova. *[2 marks]*

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Type Ia supernovae typically have a peak luminosity of around $5 \times 10^{5}\ L_S$, where L_S is the luminosity of the Sun (3.8×10^{26} W). A type Ia supernova is observed with an apparent peak brightness of $1.6 \times 10^{-6}\ \mathrm{W\ m^{-2}}$.

1b. Show that the distance to the supernova is approximately 3.1×10^{18} m. *[2 marks]*

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1c. State **one** assumption made in your calculation. *[1 mark]*

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2a. Outline, with reference to the Jeans criterion, why a cold dense gas cloud is more likely to form new stars than a hot diffuse gas cloud. *[2 marks]*

2b. Explain how neutron capture can produce elements with an atomic number greater than iron. *[2 marks]*

3a. The Sun is a second generation star. Outline, with reference to the Jeans criterion (M_J), how the Sun is likely to have been formed. *[4 marks]*

3b. Suggest how fluctuations in the cosmic microwave background (CMB) radiation are linked to the observation that galaxies collide. *[3 marks]*

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3c. Show that the critical density of the universe is *[3 marks]*

$$\frac{3H^2}{8\pi G}$$

where H is the Hubble parameter and G is the gravitational constant.

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4a. Outline, with reference to star formation, what is meant by the Jeans criterion. *[2 marks]*

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4b. In the proton–proton cycle, four hydrogen nuclei fuse to produce one nucleus of helium releasing a total of 4.3×10^{-12} J of energy. The Sun will spend 10^{10} years on the main sequence. It may be assumed that during this time the Sun maintains a constant luminosity of 3.8×10^{26} W. *[2 marks]*

Show that the total mass of hydrogen that is converted into helium while the Sun is on the main sequence is 2×10^{29} kg.

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4c. Massive stars that have left the main sequence have a layered structure with different chemical elements in different layers. Discuss this structure by reference to the nuclear reactions taking place in such stars. *[2 marks]*

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5a. Describe how some white dwarf stars become type Ia supernovae. *[3 marks]*

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5b. Hence, explain why a type Ia supernova is used as a standard candle. *[2 marks]*

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5c. Explain how the observation of type Ia supernovae led to the hypothesis that dark energy exists. *[3 marks]*

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6a. State the Jeans criterion for star formation. *[2 marks]*

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6b. Describe **three** differences between type Ia and type II supernovae. *[3 marks]*

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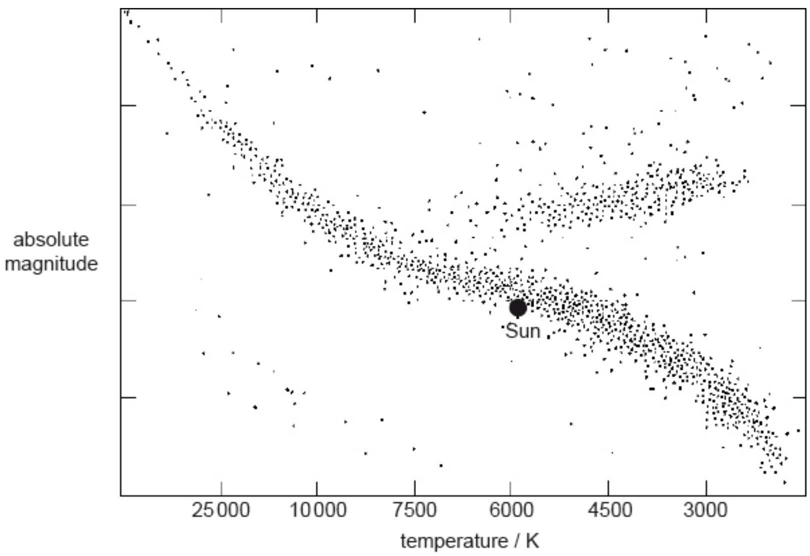
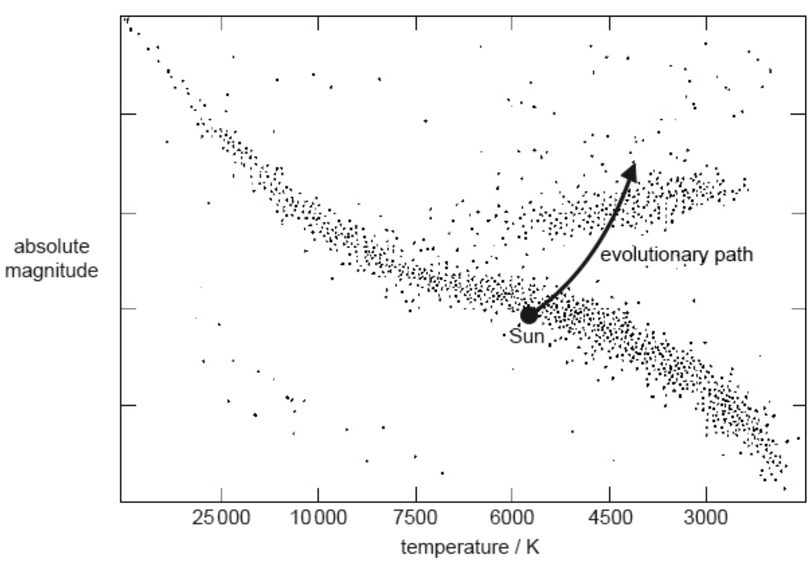
This question is about the Hertzsprung–Russell (HR) diagram and the Sun.

A Hertzsprung–Russell (HR) diagram is shown.



The Sun will remain on the main sequence of the HR diagram for about another five billion years. After this time it will become a red giant, following the evolutionary path shown in the diagram.



7a. Outline why the Sun will leave the main sequence, and describe the nuclear processes that occur as it becomes a red giant. *[4 marks]*

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7b. Describe **two** physical changes that the Sun will undergo as it enters the red giant stage. *[2 marks]*

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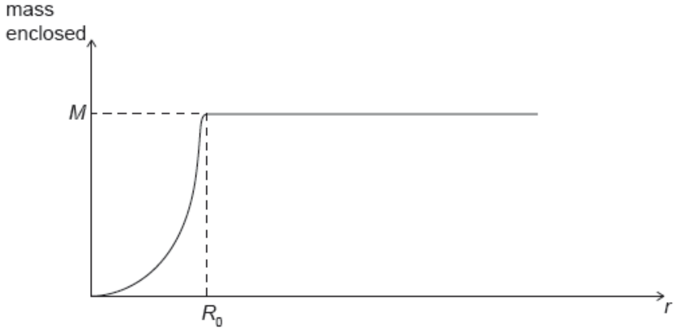
A galaxy can be modelled as a sphere of radius R_0. The distance of a star from the centre of the galaxy is r.



For this model the graph is a simplified representation of the variation with r of the mass of **visible matter** enclosed inside r.

8a. The mass of visible matter in the galaxy is M. *[1 mark]*

Show that for stars where $r > R_0$ the velocity of orbit is $v = \sqrt{\frac{GM}{r}}$.

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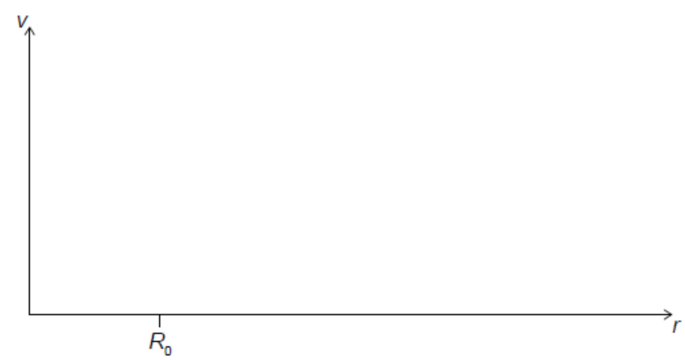
8b. Draw on the axes the observed variation with r of the orbital speed v of stars in a galaxy. *[2 marks]*

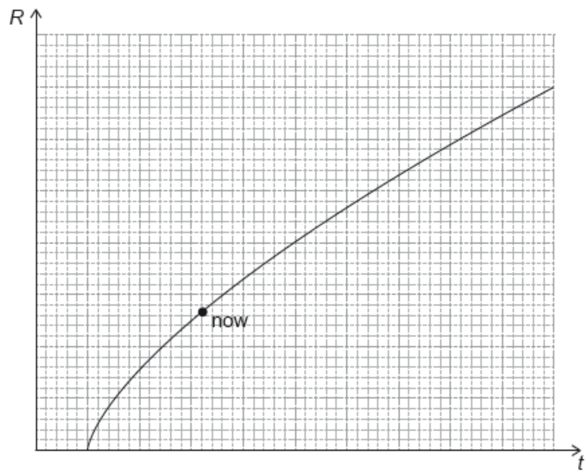


8c. Explain, using the equation in (a) and the graphs, why the presence of visible matter alone cannot account for the velocity of stars when $r > R_0$. *[2 marks]*

9a. Explain the evidence that indicates the location of dark matter in galaxies. *[3 marks]*

9b. Outline why a hypothesis of dark energy has been developed. *[3 marks]*

10a. The graph shows the variation with time t of the cosmic scale factor R in the flat model of the universe in which dark energy is ignored. *[1 mark]*



On the axes above draw a graph to show the variation of R with time, when dark energy is present.

Recent evidence from the Planck observatory suggests that the matter density of the universe is $\rho_m = 0.32\ \rho_c$, where $\rho_c \approx 10^{-26}\ kg\ m^{-3}$ is the critical density.

10b. The density of the observable matter in the universe is only 0.05 ρ_c. Suggest how the remaining 0.27 ρ_c is accounted for. *[1 mark]*

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10c. The density of dark energy is $\rho_\Lambda c^2$ where $\rho_\Lambda = \rho_c - \rho_m$. Calculate the amount of dark energy in 1 m^3 of space. *[2 marks]*

11a. Derive, using the concept of the cosmological origin of redshift, the relation *[2 marks]*

$T \propto \frac{1}{R}$

between the temperature T of the cosmic microwave background (CMB) radiation and the cosmic scale factor R.

11b. The present temperature of the CMB is 2.8 K. This radiation was emitted when the universe was smaller by a factor of 1100. Estimate the temperature of the CMB at the time of its emission. *[2 marks]*

11c. State how the anisotropies in the CMB distribution are interpreted. *[1 mark]*

12a. Describe what is meant by dark matter. *[2 marks]*

12b. The distribution of mass in a spherical system is such that the density ρ varies with distance r from the centre as *[1 mark]*

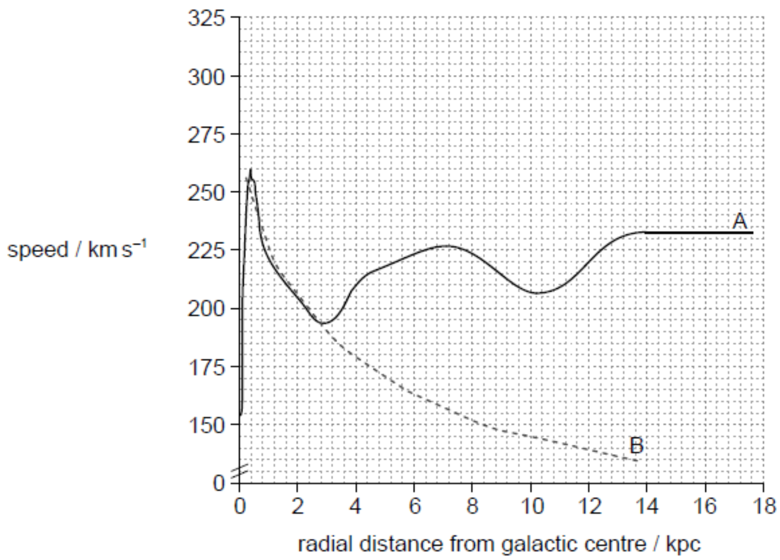
$\rho = \frac{k}{r^2}$

where k is a constant.

Show that the rotation curve of this system is described by

v = constant.

12c. Curve A shows the actual rotation curve of a nearby galaxy. Curve B shows the predicted rotation curve based on the visible stars in the galaxy. *[2 marks]*



Explain how curve A provides evidence for dark matter.

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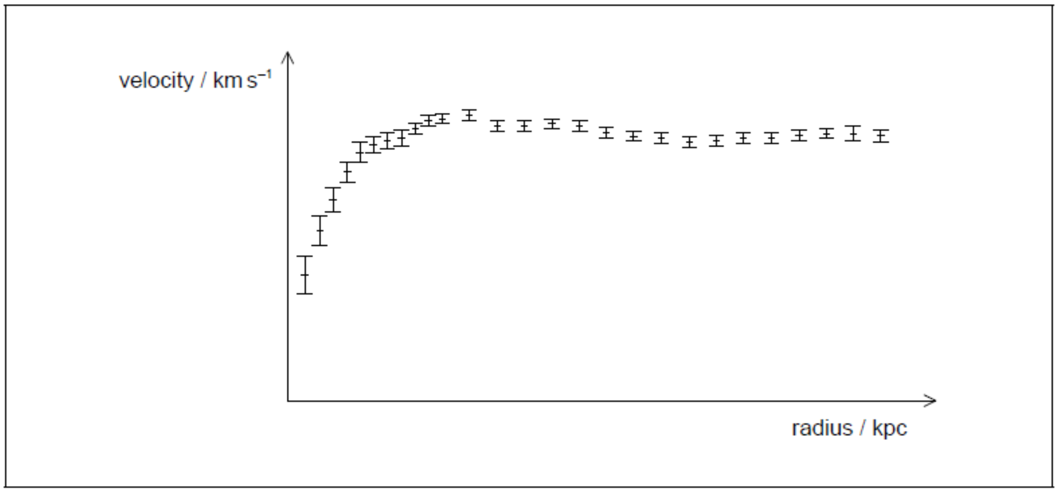
The graph shows the observed orbital velocities of stars in a galaxy against their distance from the centre of the galaxy. The core of the galaxy has a radius of 4.0 kpc.



13a. Calculate the rotation velocity of stars 4.0 kpc from the centre of the galaxy. The average density of the galaxy is 5.0×10^{-21} kg m^{-3}. *[2 marks]*

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13b. Explain why the rotation curves are evidence for the existence of dark matter. *[2 marks]*

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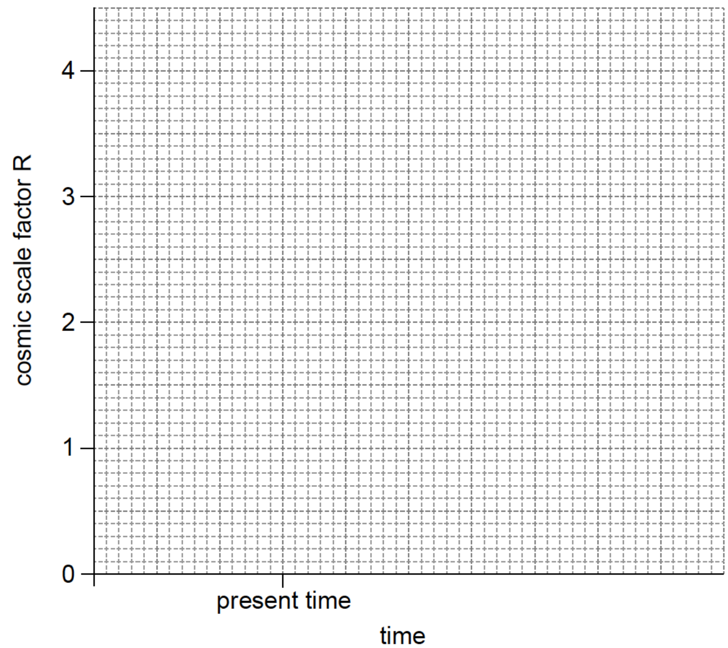
The Hot Big Bang model suggests several outcomes for the universe. There is now evidence that dark energy and dark matter exist.



14a. On the axes, sketch a graph of the variation of cosmic scale factor with time for *[3 marks]*

(i) a closed universe without dark energy. Label this curve C.

(ii) an accelerating universe with dark energy. Label this curve A.

14b. Explain **one** experimental observation that supports the presence of dark **matter**. *[2 marks]*

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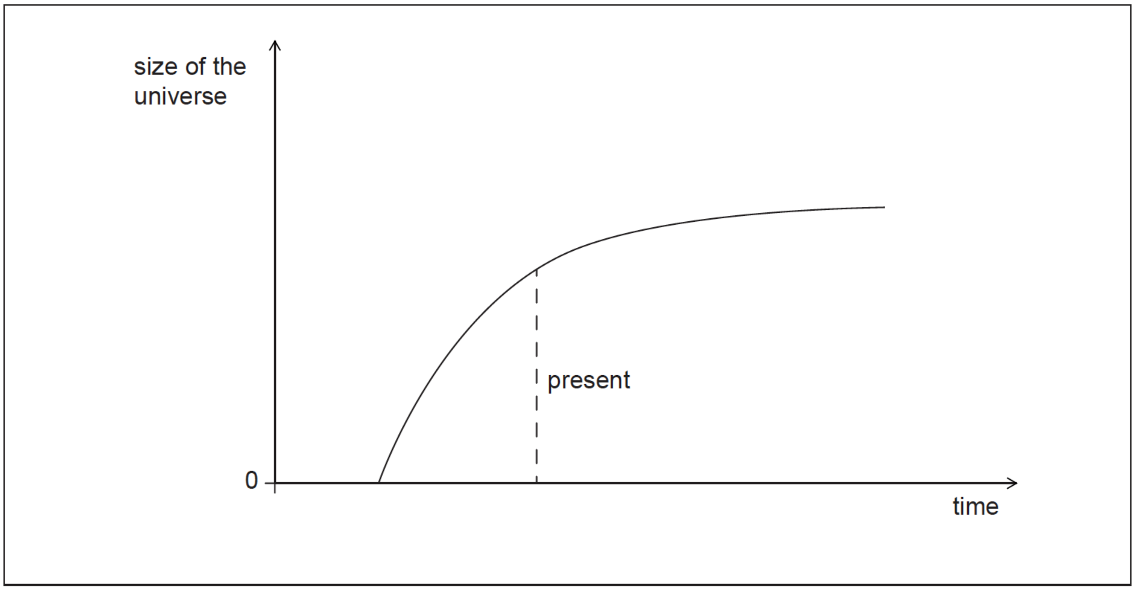
This question is about the development of the universe.

The graph shows one possible way in which the universe is thought to change with time. This type of universe is known as a fl at universe.



15a. On the graph, draw lines to show the variation with time of the size of the universe for both a closed universe and an open universe. Label your line for the closed universe C and your line for the open universe O. *[2 marks]*

15b. Explain how the open and closed outcomes for the universe depend on the critical density of matter in the universe. *[3 marks]*

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15c. State **one** reason why it is difficult to determine the density of the universe. *[1 mark]*

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This question is about cosmology.

16a. Theoretical studies indicate that the universe may be open, closed or flat. *[4 marks]*

(i) State, by reference to critical density, the condition that must be satisfied for the universe to be flat.

(ii) In a flat universe, the rate of expansion would be slowing down. Suggest a reason for this.

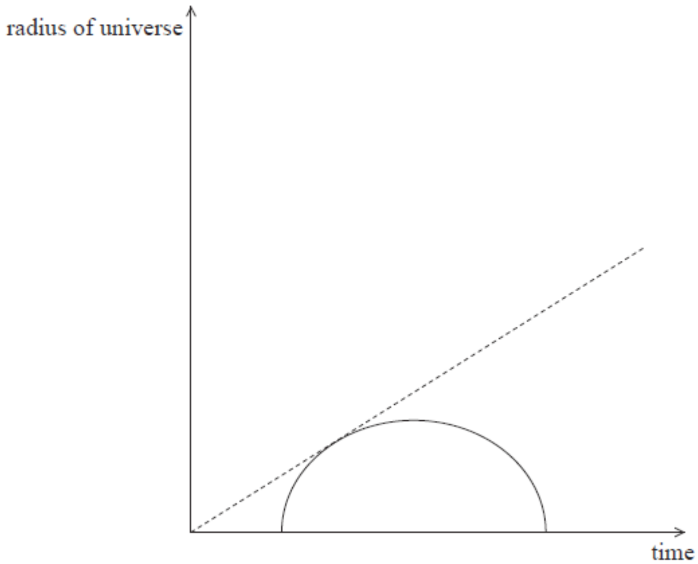
(iii) Outline why it has been difficult to determine whether the universe is open, closed or flat.

16b. Outline **one** piece of experimental evidence that supports the fact that the universe is expanding. *[2 marks]*

This question is about the development of the universe.

17a. Define, with reference to the flat model of the universe, *critical density*. *[2 marks]*

17b. The diagram represents how the universe might develop if its density were greater than the critical density. *[3 marks]*



The dotted line represents the development of the universe if the density of the universe were zero.

On the diagram above,

(i) label with the letter N the present time.

(ii) draw a line labelled F to represent the development of the universe corresponding to a flat universe.

(iii) draw a line labelled O to represent the development of the universe corresponding to the universe if its density were less than the critical density.

This question is about the development of the universe.

18a. Light from distant galaxies, as seen by an observer on Earth, shows a red-shift. Outline why this observation suggests that the universe is expanding. *[2 marks]*

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18b. The future development of the universe is determined by the relationship between the apparent density of the universe and the critical density. *[5 marks]*

(i) Define the term *critical density*.

(ii) Discuss how the density of the universe determines its future development. Your discussion should include **one** problem associated with determining the density of the universe.

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This question is about the density of the universe.

19a. Explain, with reference to the possible fate of the universe, the significance of the critical density of matter in the universe. *[3 marks]*

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19b. Suggest **one** reason why it is difficult to estimate the density of matter in the universe. *[2 marks]*

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