TD *[75 marks]*

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.

1a. Identify whether star X is on the main sequence. Assume that $n = 3.5$ in the mass–luminosity relation. *[2 marks]*

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1b. (i) State the evolution of star X. *[3 marks]*

(ii) Explain the eventual fate of star X.

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This question is about Hubble's law.

2a. The light from distant galaxies is red-shifted. Explain how this red-shift arises. *[3 marks]*

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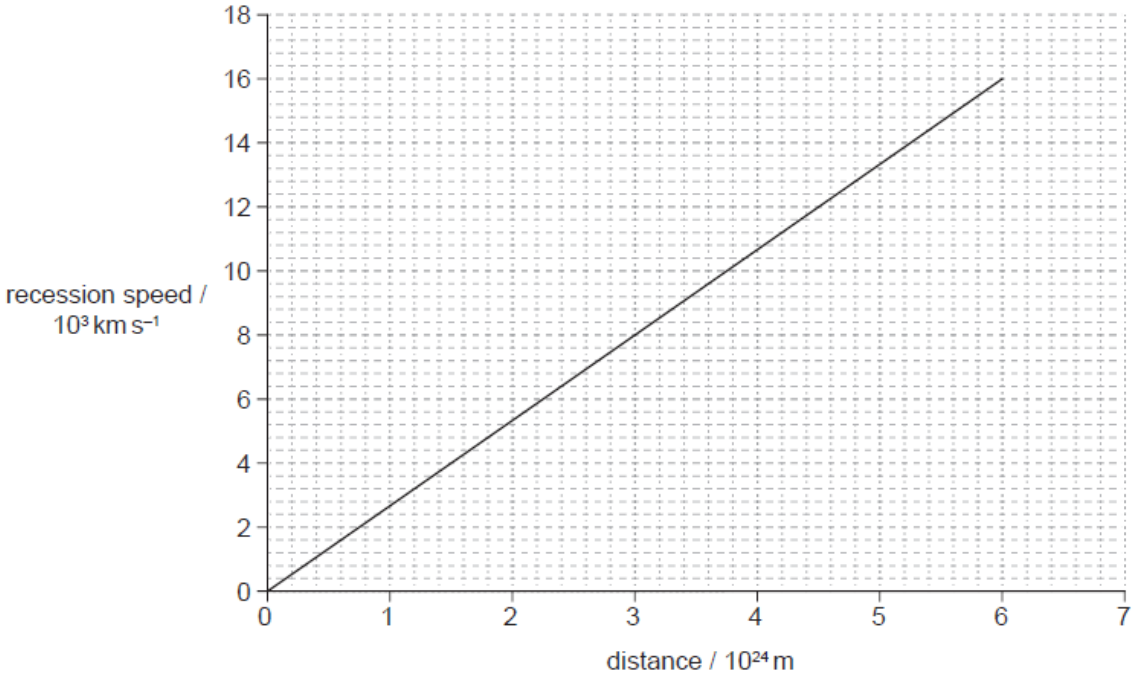
2b. The graph shows the variation of recession speed with distance from Earth for some galactic clusters. *[4 marks]*



(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).

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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.

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

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

3a. (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.

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3b. (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.

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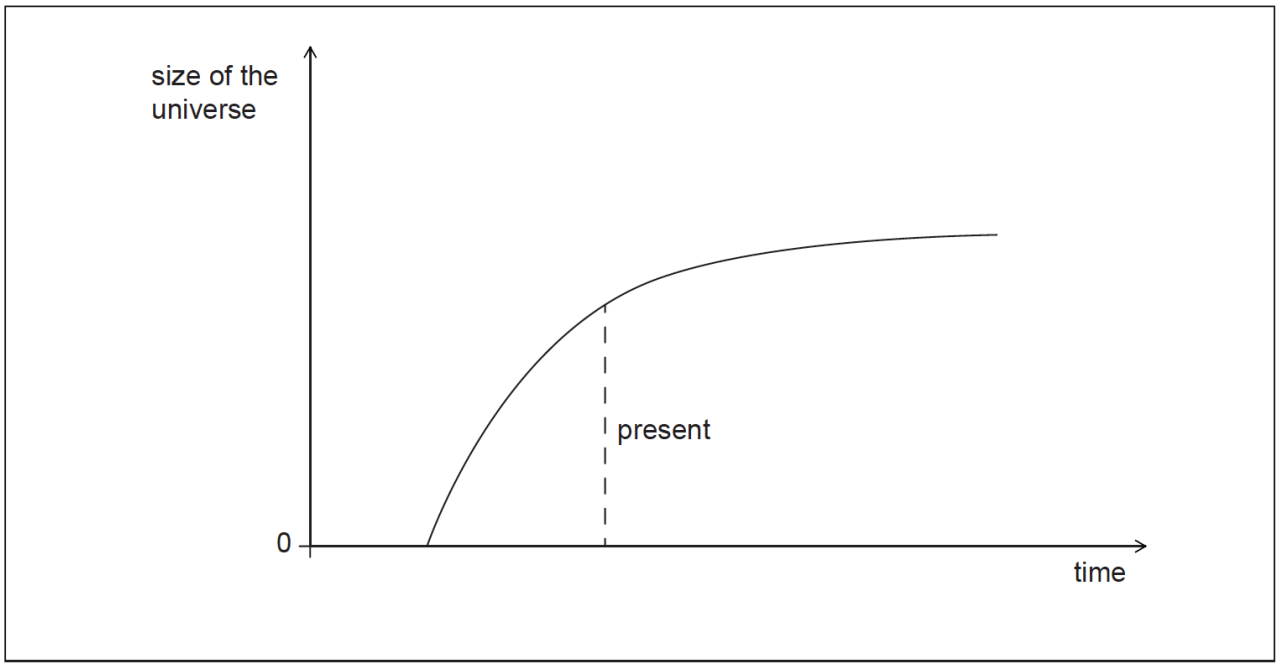
This question is about the development of the universe.

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.



4a. 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]*

4b. 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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4c. State **one** reason why it is difficult to determine the density of the universe. *[1 mark]*

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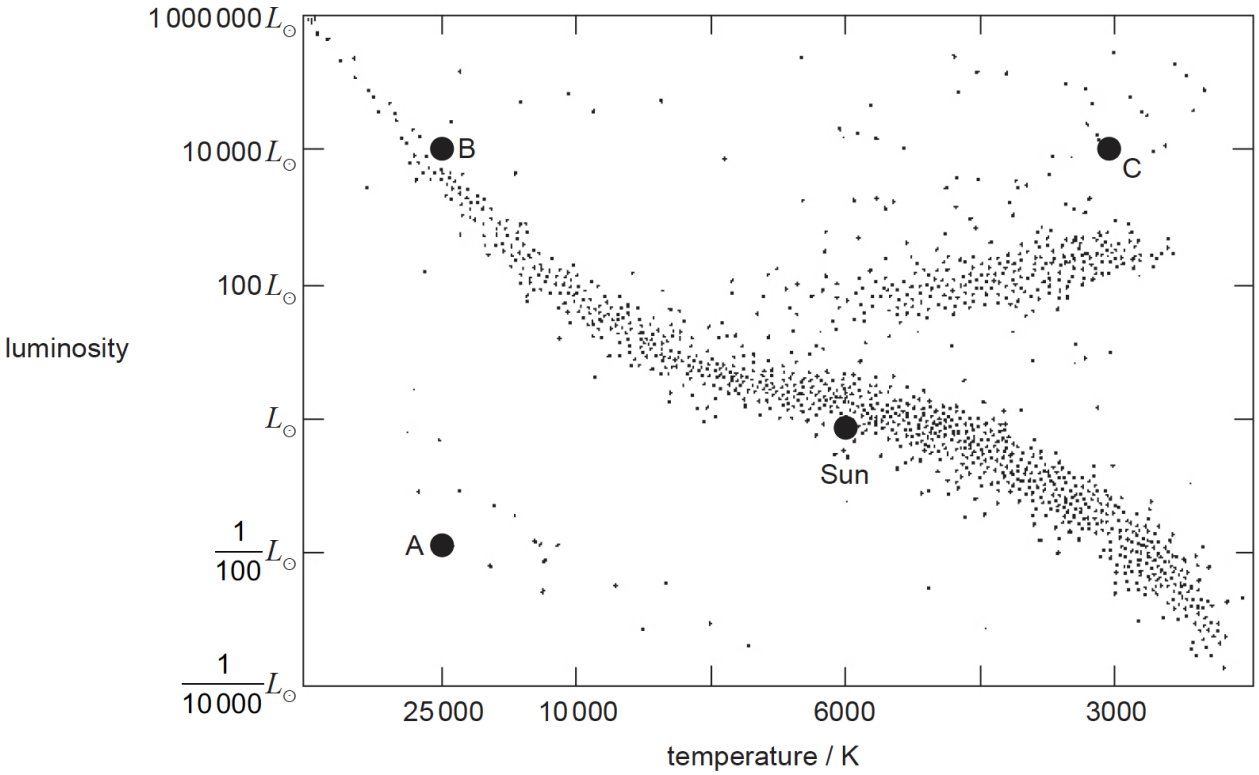
This question is about stars.

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



5a. State the star type for A, B and C. *[3 marks]*

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5b. The apparent brightness of C is 3.8 \(\times \) 10^{-10} Wm^{-2}. The luminosity of the Sun is 3.9 \(\times \) 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.

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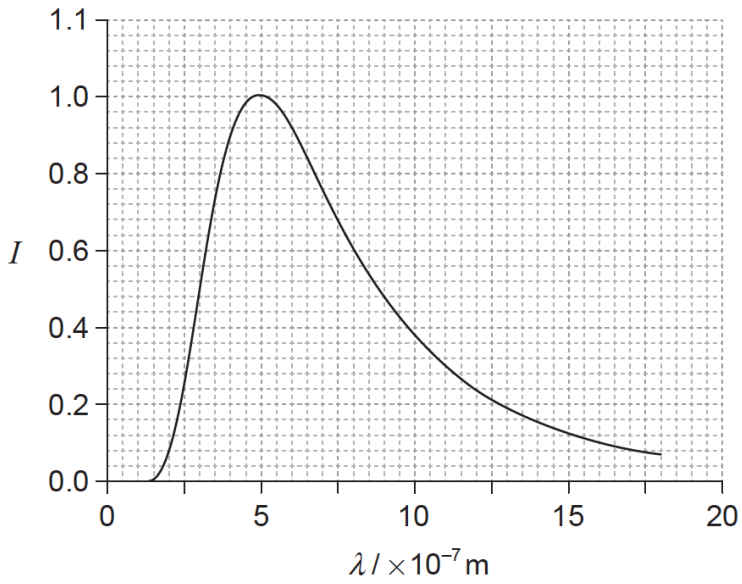
5c. The graph shows the variation with wavelength λ of the intensity I of the radiation emitted by 1.0m^2 of the surface of the Sun. The curve of the graph has been adjusted so that the maximum intensity is 1. *[2 marks]*



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.

6a. State what is meant by the expansion of the universe. *[1 mark]*

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6b. 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.

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This question is about stellar evolution.

7a. 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]*

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7b. 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.

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7c. Explain why a white dwarf maintains a constant radius. *[2 marks]*

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This question is about Hubble's law.

8a. 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.

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8b. Light of wavelength 620 nm is emitted from a distant galaxy. The shift in wavelength measured on Earth is 35 nm. *[1 mark]*
Determine the distance to the galaxy using a Hubble constant of 68 km $s^{-1}Mpc^{-1}$.

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9. This question is about comets. *[2 marks]*

Outline the nature of a comet.

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10. This question is about the life history of stars. *[3 marks]*

Outline, with reference to pressure, how a star on the main sequence maintains its stability.

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This question is about the life history of stars.

11a. Outline, with reference to pressure, how a star on the main sequence maintains its stability. *[3 marks]*

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11b. A star with a mass equal to that of the Sun moves off the main sequence. Outline the main processes of nucleosynthesis that occur in the core of this star before and after this change. *[2 marks]*

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11c. Compare the fate of the star in (b) with that of a star of much greater mass. *[3 marks]*

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This question is about stellar distances.

12a. The star Sirius A is 3 pc from Earth. The apparent brightness of Sirius A is $1.2\times10^{-7}\text{Wm}^{-2}$. Determine the luminosity of Sirius A. *[2 marks]*

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12b. The luminosity of the Sun is 3.8×10^{26} W. Determine the mass of Sirius A relative to the mass of the Sun. (Assume that $n=3.5$ in the mass–luminosity relation.) *[2 marks]*

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This question is about the structure of the universe.

13a. (i) State, in terms of the arrangement of galaxies, the present large-scale distribution of mass in the universe. *[2 marks]*

(ii) State how the separation of distant galaxies is changing with time.

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13b. State and explain the observational evidence for your answer to (a)(ii). *[3 marks]*

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