

**Option F — Astrophysics**

**F1.** This question is about measuring stellar distances.

(a) Describe what is meant by

(i) apparent brightness.

[1]

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(ii) apparent magnitude.

[2]

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(iii) absolute magnitude.

[1]

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(b) State the property of a star that is most closely related to its absolute magnitude.

[1]

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(c) The star Ross 128 has an apparent magnitude that is less than its absolute magnitude. Explain, with reference to this statement, why the method of stellar parallax may be used to measure the distance of Ross 128 from Earth.

[3]

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*(Question F1 continued)*

- (d) Describe how the observed spectrum of very distant stars can be used to estimate their absolute magnitude. [4]

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- (e) The apparent brightness of Ross 128 is  $7.9 \times 10^{-15} \text{ W m}^{-2}$  and its luminosity is  $1.1 \times 10^{21} \text{ W}$ . Determine in parsecs, the distance of Ross 128 from Earth. [3]

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**F2.** This question is about the Doppler shift and the expansion of the universe.

When light from distant galaxies is analysed, the spectral lines are observed to have been Doppler shifted.

(a) State the reason for this Doppler shift. [1]

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(b) Penzias and Wilson discovered that there was a uniform source of microwave radiation from every direction in the universe. Explain how this discovery supports the theory that the universe is expanding. [2]

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(c) It is suggested that the rate of expansion of the universe might have been gradually increasing since the Big Bang. State and describe the effect, if any, that this theory would predict about the observed Doppler shift of light from distant galaxies. [2]

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(d) A particular line in the absorption spectrum of helium has a wavelength 468.6 nm as measured in the laboratory. The line as measured in the spectrum of a star in a distant galaxy has a wavelength of 502.1 nm. Determine the speed of the star with respect to the Earth. [3]

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*(Question F2 continued)*

(e) A star in a different galaxy has a recession speed of  $2.3 \times 10^3 \text{ km s}^{-1}$ . The galaxy is 31 Mpc from Earth. Use this data to estimate

(i) a value for the Hubble constant  $H_0$ . [2]

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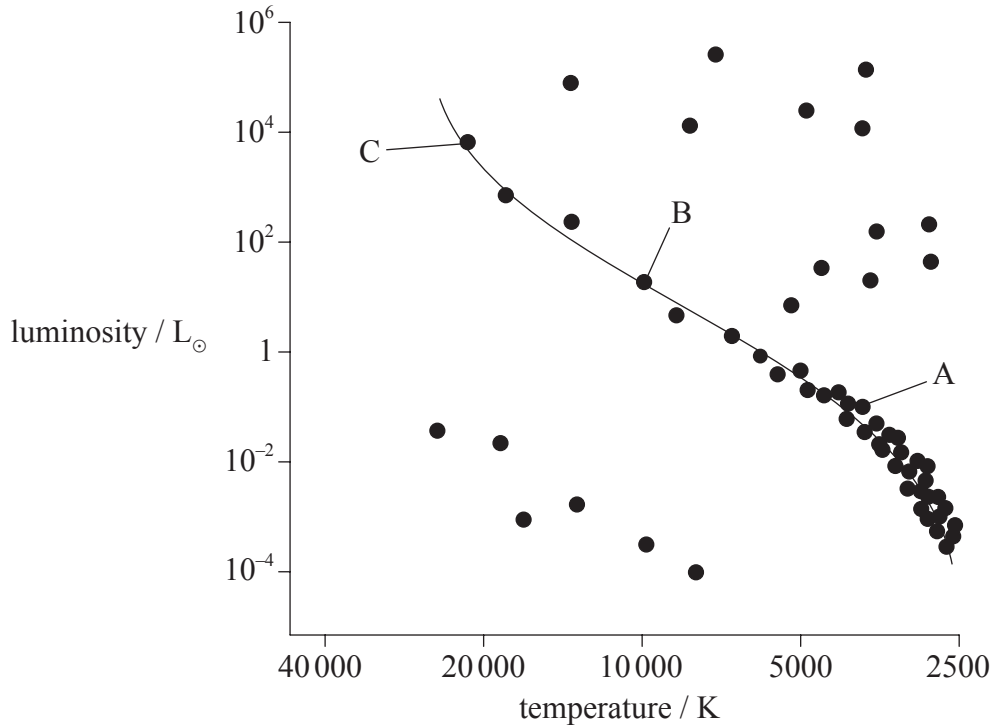
(ii) the age of the universe in seconds. [2]

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F3. This question is about stellar evolution.

The diagram below represents a Hertzsprung-Russell (HR) diagram. The three identified stars (A, B and C) are all on the main sequence.



(a) Explain which of these stars is most likely to evolve to a white dwarf star. [2]

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(b) Draw and label the evolutionary path of the star as it evolves to a white dwarf star. [1]



**Option G — Relativity**

**G1.** This question is about Special Relativity.

Two inertial observers, Alice and Bob, are moving towards each other along the same straight line with constant relative speed  $v$ . On either side of Alice are two lamps, X and Y, equal distances away from Alice and at rest in her reference frame.

The diagram below represents the situation according to Bob’s reference frame.



Alice has a switch that controls each of the lamps. The lamps are initially switched off.

(a) Describe what is meant by an inertial reference frame. [1]

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(b) Alice closes the switch, producing an electromagnetic signal that travels from her to the lamps. When either lamp receives the electromagnetic signal it turns on. State and explain the order in which the signal arrives at the lamps (X first, Y first or simultaneously)

(i) according to Alice. [2]

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(ii) according to Bob. [2]

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(Question G1 continued)

- (c) Explain, in terms of the path taken by electromagnetic waves from the switch to Bob, why Bob receives light from lamp Y before light from lamp X. [2]

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- (d) Two events are defined as follows:
  - event P: the switch for lamp X is closed
  - event Q: the light from lamp X arrives at Alice.

Alice measures a time  $t_A$  and Bob measures a time  $t_B$  between these two events.

- (i) Discuss, with reference to proper time, the difference in value between  $t_A$  and  $t_B$ . [3]

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- (ii) State and explain whether your answer to (d)(i) would be different for the situation in which Alice was moving away from Bob at speed  $v$  as measured by Bob. [2]

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*(Question G1 continued)*

(e) Alice measures the distance between the lamps to be 30.0 m. The speed  $v$  is  $0.90c$ .

(i) Explain whether the proper length between the two lamps is greater than, equal to **or** less than 30.0 m. [1]

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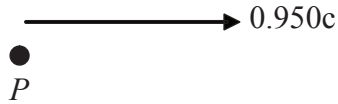
(ii) Calculate the distance between the lamps, as measured by Bob. [2]

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**G2.** This question is about relativistic velocity addition and relativistic mass.

A particle,  $P$ , is moving at constant velocity  $0.950c$  along the  $x$ -axis, with respect to an inertial laboratory reference frame. The diagram below represents this situation according to the laboratory reference frame.



The particle decays. One of the decay products is a smaller particle  $Q$  of rest mass  $940 \text{ MeV } c^{-2}$  that is ejected at velocity  $0.900c$  along the  $x$ -axis relative to  $P$ 's reference frame.

The diagram below represents the situation according to  $P$ 's reference frame. The other decay products are not shown.



(a) Calculate the velocity of particle  $Q$  as measured in the laboratory reference frame. [2]

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(b) Calculate the difference between the mass of particle  $Q$  in  $P$ 's reference frame and the laboratory reference frame. [3]

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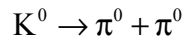
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**G3.** This question is about energy and momentum.

A stationary  $K^0$  particle decays into two  $\pi^0$  pions as represented by the following equation.



The following data are available.

$$\text{Rest mass of the } K^0 = 498 \text{ MeV c}^{-2}$$

$$\text{Rest mass of the } \pi^0 = 135 \text{ MeV c}^{-2}$$

- (a) Deduce that the momentum of each of the pions is  $209 \text{ MeV c}^{-1}$ . [3]

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- (b) Using your answer in (a), calculate the speed of each of the pions. [3]

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**G4.** This question is about spacetime and black holes.

(a) State

(i) what is meant by spacetime. [1]

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(ii) the path followed by a point mass moving through spacetime. [1]

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(b) Use your answers to (a)(i) and (ii) to describe what is meant by a black hole. [2]

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