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**Physics**  
**Standard level**  
**Paper 3**

2 May 2023

**Zone A** afternoon | **Zone B** morning | **Zone C** morning

Candidate session number

1 hour

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**Instructions to candidates**

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[35 marks]**.

Section A	Questions
Answer all questions.	1 – 2

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Relativity	3 – 5
Option B — Engineering physics	6 – 7
Option C — Imaging	8 – 10
Option D — Astrophysics	11 – 13

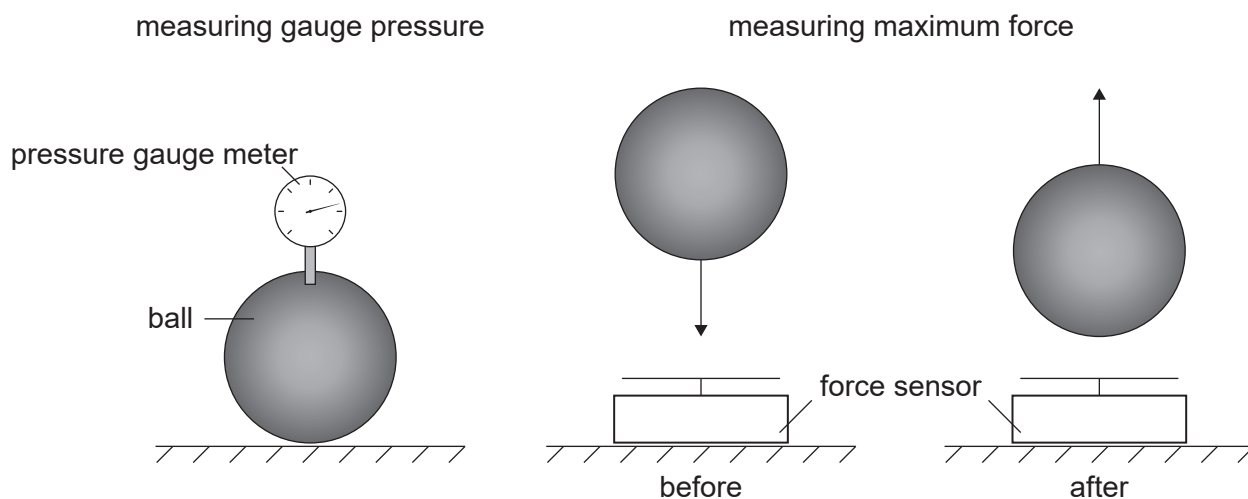


### Section A

Answer **all** questions. Answers must be written within the answer boxes provided.

1. A student investigates the relationship between the pressure in a ball and the maximum force that the ball produces when it rebounds.

A pressure gauge measures a difference  $\Delta p$  between the atmospheric pressure and the pressure in the ball. A force sensor measures the maximum force  $F_{\max}$  exerted on it by the ball during the rebound.



- (a) State **one** variable that needs to be controlled during the investigation.

[1]

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(This question continues on the following page)



**(Question 1 continued)**

The student collects the following data.

Gauge pressure $\Delta p$ / kPa	Maximum force $F_{\max}$ / N
10	108
20	133
30	158
40	170
50	188
60	192
70	206
80	220

The student initially hypothesizes that  $F_{\max}$  is proportional to  $\Delta p$ .

- (b) Deduce, using **two** suitable data points from the table, that the student's initial hypothesis is not supported.

[3]

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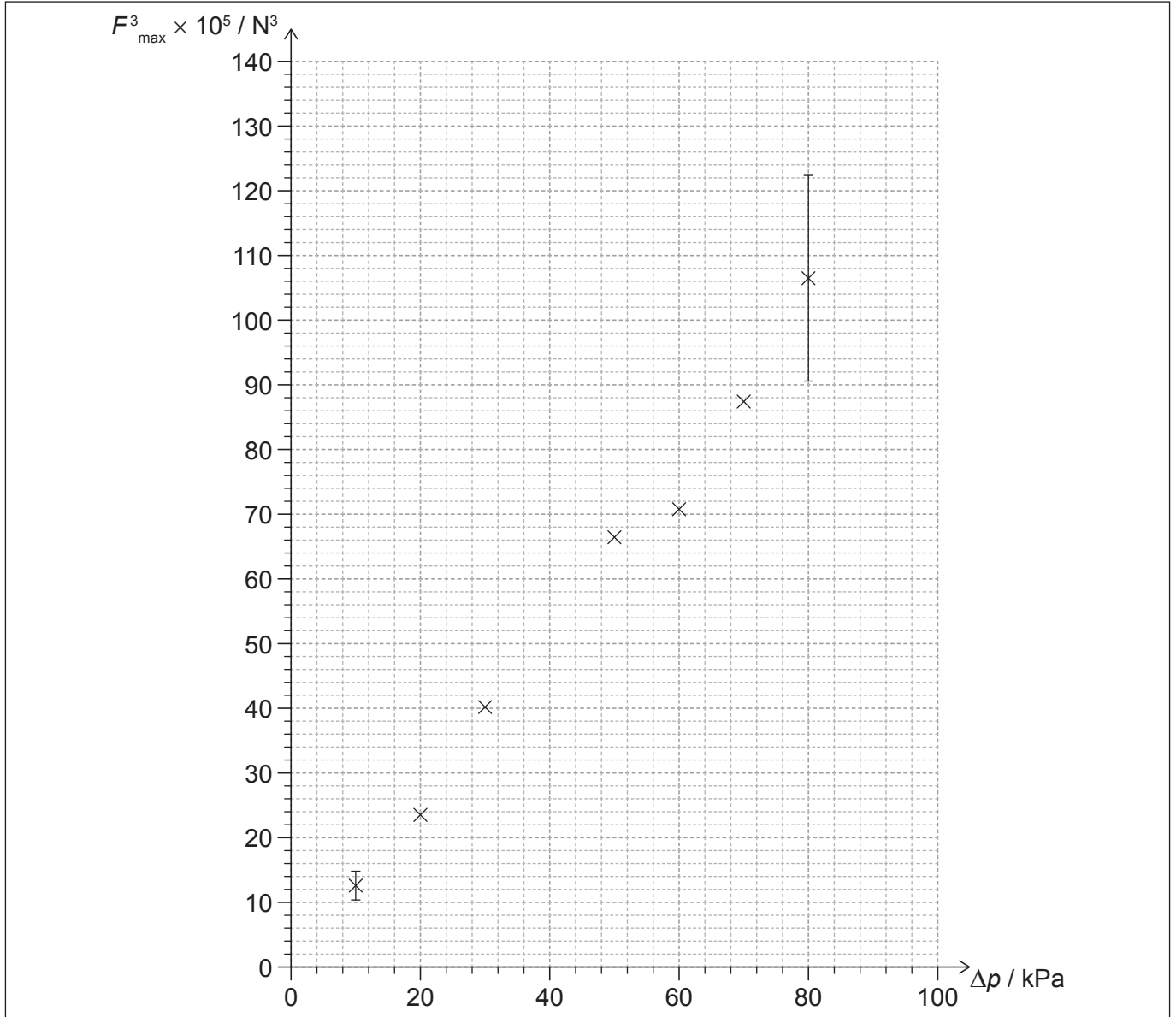
**(This question continues on the following page)**



**(Question 1 continued)**

The student now proposes that  $F_{\max}^3 = k\Delta p$ .

The student plots a graph of the variation of  $F_{\max}^3$  with  $\Delta p$ .



(c) (i) State the unit for  $k$ . [1]

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(ii) Plot on the graph the position of the missing point for the  $\Delta p$  value of 40 kPa. [1]

**(This question continues on the following page)**



**(Question 1 continued)**

The percentage uncertainty in  $F_{\max}$  is  $\pm 5\%$ . The error bars for  $F_{\max}^3$  at  $\Delta p = 10 \text{ kPa}$  and  $\Delta p = 80 \text{ kPa}$  are shown.

- (d) (i) Calculate the absolute uncertainty in  $F_{\max}^3$  for  $\Delta p = 30 \text{ kPa}$ . State an appropriate number of significant figures for your answer. [3]

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- (ii) Plot the absolute uncertainty determined in part (d)(i) as an error bar on the graph. [1]

- (iii) Explain why the new hypothesis is supported. [1]

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2. A student conducts an experiment to determine the specific heat capacity of a metal cube. The cube is heated in a beaker of boiling water to a temperature of  $100^{\circ}\text{C}$  and then quickly transferred into an insulated vessel of negligible thermal capacity. The vessel contains water at  $20^{\circ}\text{C}$  and of known specific heat capacity.

(a) State one other measurement that the student will need to make. [1]

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(b) Suggest one modification that the student can make to reduce the fractional uncertainty for the change in temperature of the metal cube. [1]

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(c) Some water from the beaker is accidentally transferred with the cube.  
Discuss how this will affect the value of the calculated specific heat capacity of the cube. [2]

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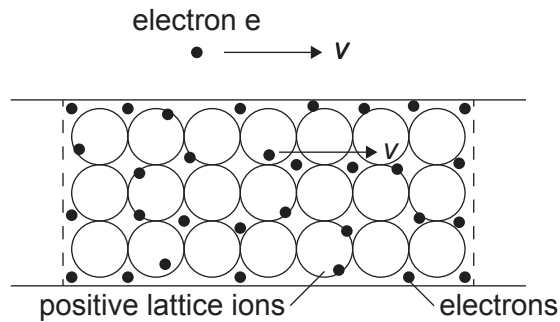


### Section B

Answer **all** of the questions from **one** of the options. Answers must be written within the answer boxes provided.

#### Option A — Relativity

- 3. A wire carries an electric current. An external electron  $e$  moves with the drift velocity  $v$  of the electrons in the wire. Observer  $O$  is at rest relative to the wire.



- (a) State what is meant by a frame of reference. [1]

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- (b) State and explain the nature of the electromagnetic force acting on electron  $e$  in the frame of reference of

- (i) observer  $O$ . [2]

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- (ii) electron  $e$ . [2]

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(Option A continues on the following page)



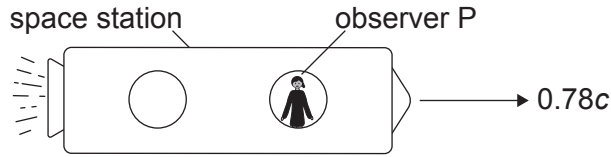
32EP07

Turn over



(Option A continued)

4. Star A and star B are separated by a fixed distance of 4.8 light years as measured in the reference frame in which they are stationary. An observer P at rest in a space station moves to the right with speed  $0.78c$  relative to the stars. A shuttle S travels from star A to star B at a speed of  $0.30c$  relative to the stars.



- (a) State the value of the maximum distance between the stars that can be measured in any reference frame. [1]

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- (b) Write down the speed of shuttle S relative to observer P using Galilean relativity. [1]

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- (c) Calculate the distance between star A and star B relative to observer P. [2]

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(Option A continues on the following page)



**(Option A, question 4 continued)**

- (d) Show that the speed of shuttle S relative to observer P is approximately  $0.6c$ . [2]

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- (e) Calculate the time, according to observer P, that the shuttle S takes to travel from star A to star B. [2]

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- (f) Identify and explain the reference frame in which the proper time for shuttle S to journey from star A to star B can be measured. [2]

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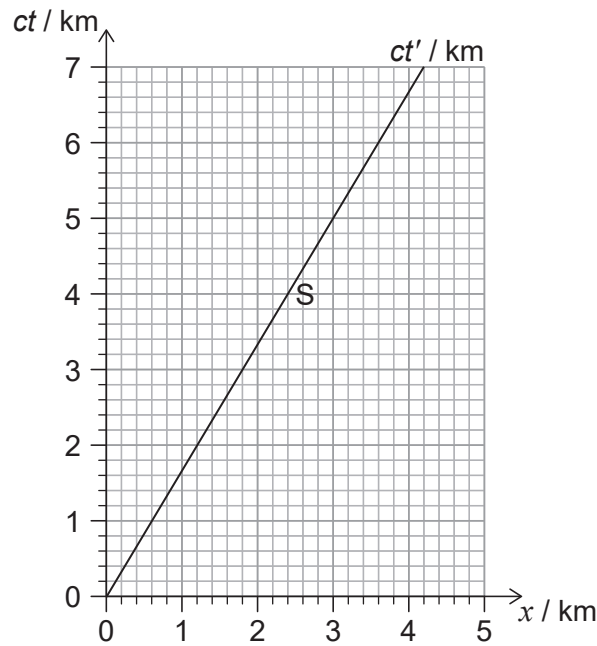
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**(Option A continues on the following page)**



(Option A continued)

5. The spacetime diagram shows the Earth frame with the worldline of a spaceship S moving away from Earth.  $ct' = 0$  when  $ct = 0$ .



- (a) Determine the speed of the spaceship relative to Earth. [1]

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A flash of light sent by an Earth observer at  $ct = 2.0$  km is directed towards the spaceship.

- (b) Estimate, using the spacetime diagram, the time in seconds when the flash of light reaches the spaceship according to the Earth observer. [2]

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(Option A continues on the following page)



**(Option A, question 5 continued)**

- (c) Determine the time coordinate  $ct'$  when the flash of light reaches the spaceship, according to an observer at rest in the spaceship.

[2]

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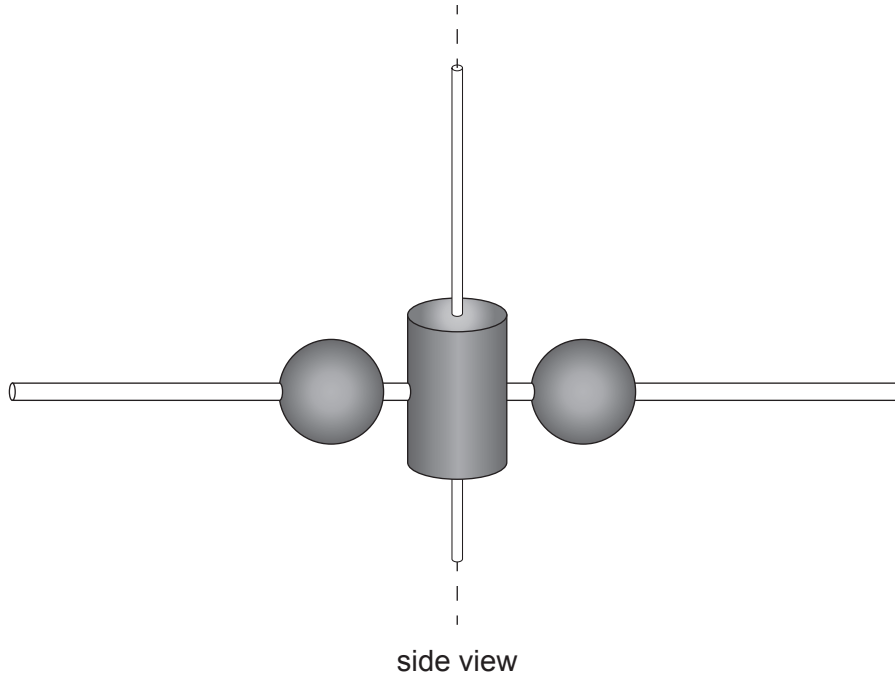
**End of Option A**



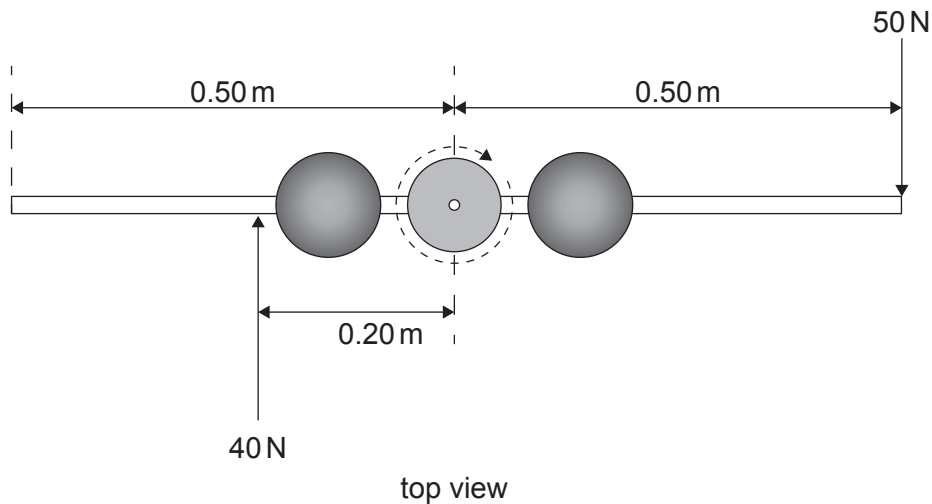
**Option B — Engineering physics**

6. A student models a rotating dancer using a system that consists of a vertical cylinder, a horizontal rod and two spheres.

The cylinder rotates from rest about the central vertical axis. A rod passes through the cylinder with a sphere on each side of the cylinder. Each sphere can move along the rod. Initially the spheres are close to the cylinder.



A horizontal force of 50 N is applied perpendicular to the rod at a distance of 0.50 m from the central axis. Another horizontal force of 40 N is applied in the opposite direction at a distance of 0.20 m from the central axis. Air resistance is negligible.



(Option B continues on the following page)



**(Option B, question 6 continued)**

- (a) Show that the net torque on the system about the central axis is approximately 30 Nm. [1]

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- (b) The system rotates from rest and reaches a maximum angular speed of  $20 \text{ rad s}^{-1}$  in a time of 5.0 s. Calculate the angular acceleration of the system. [1]

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- (c) Determine the moment of inertia of the system about the central axis. [2]

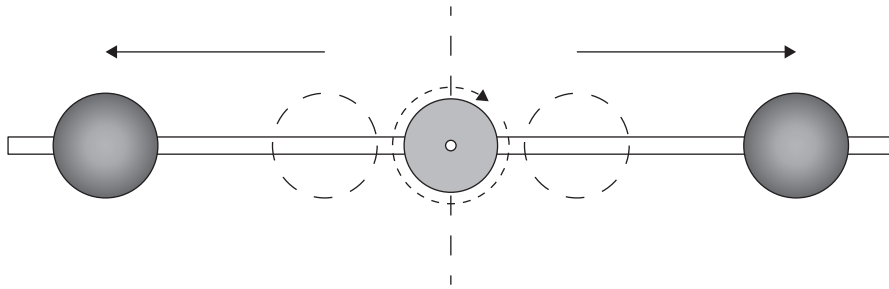
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**(Option B continues on the following page)**



(Option B, question 6 continued)

- (d) When the system has reached its maximum angular speed, the two forces are removed. The spheres now move outward, away from the central axis.



- (i) Outline why the angular speed  $\omega$  decreases when the spheres move outward. [2]

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- (ii) Show that the rotational kinetic energy is  $\frac{1}{2}L\omega$  where  $L$  is the angular momentum of the system. [1]

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- (iii) When the spheres move outward, the angular speed decreases from  $20 \text{ rad s}^{-1}$  to  $12 \text{ rad s}^{-1}$ . Calculate the percentage change in rotational kinetic energy that occurs when the spheres move outward. [2]

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(Option B continues on the following page)



**(Option B, question 6 continued)**

(e) Outline one reason why this model of a dancer is unrealistic.

[1]

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**(Option B continues on the following page)**



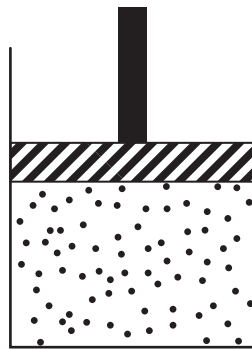
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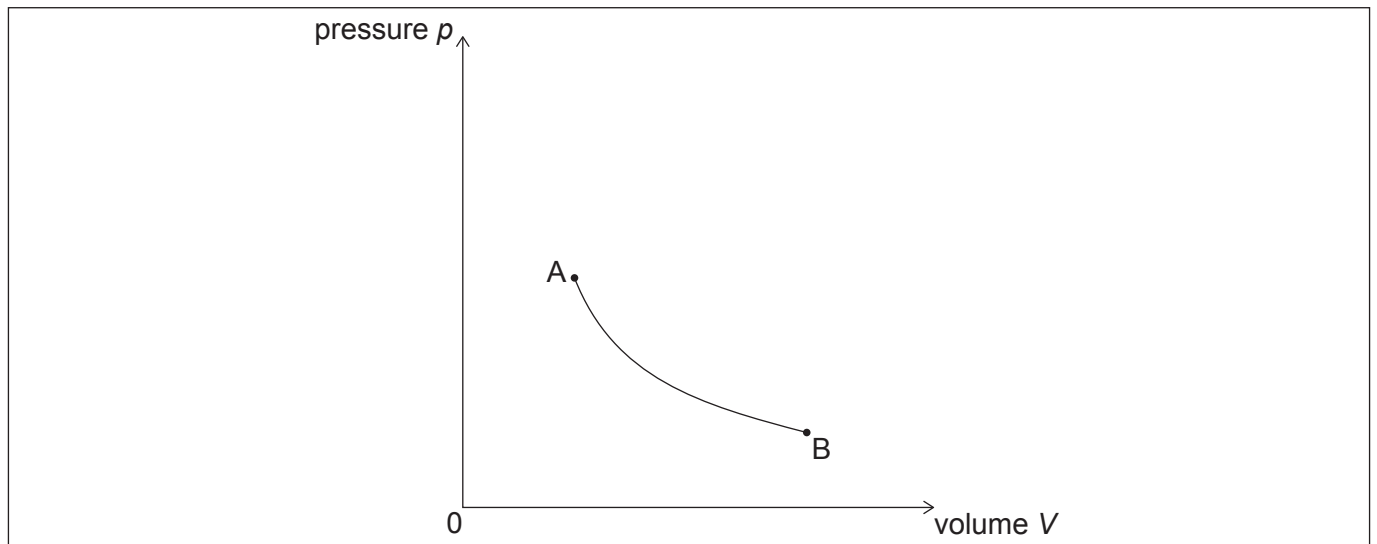
(Option B continued)

7. A frictionless piston traps a fixed mass of an ideal gas. The gas undergoes three thermodynamic processes in a cycle.



The initial conditions of the gas at A are:

volume =  $0.330 \text{ m}^3$   
pressure =  $129 \text{ kPa}$   
temperature =  $27.0 \text{ }^\circ\text{C}$



Process AB is an isothermal change, as shown on the pressure volume ( $pV$ ) diagram, in which the gas expands to three times its initial volume.

- (a) Calculate the pressure of the gas at B. [2]

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(Option B continues on the following page)



**(Option B, question 7 continued)**

The gas now undergoes adiabatic compression BC until it returns to the initial volume. To complete the cycle, the gas returns to A via the isovolumetric process CA.

- (b) Sketch, on the  $pV$  diagram, the remaining two processes BC and CA that the gas undergoes. [2]
- (c) Show that the temperature of the gas at C is approximately  $350^{\circ}\text{C}$ . [2]

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- (d) Explain why the change of entropy for the gas during the process BC is equal to zero. [1]

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- (e) Explain why the work done by the gas during the isothermal expansion AB is less than the work done on the gas during the adiabatic compression BC. [1]

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- (f) The quantity of trapped gas is 53.2 mol. Calculate the thermal energy removed from the gas during process CA. [2]

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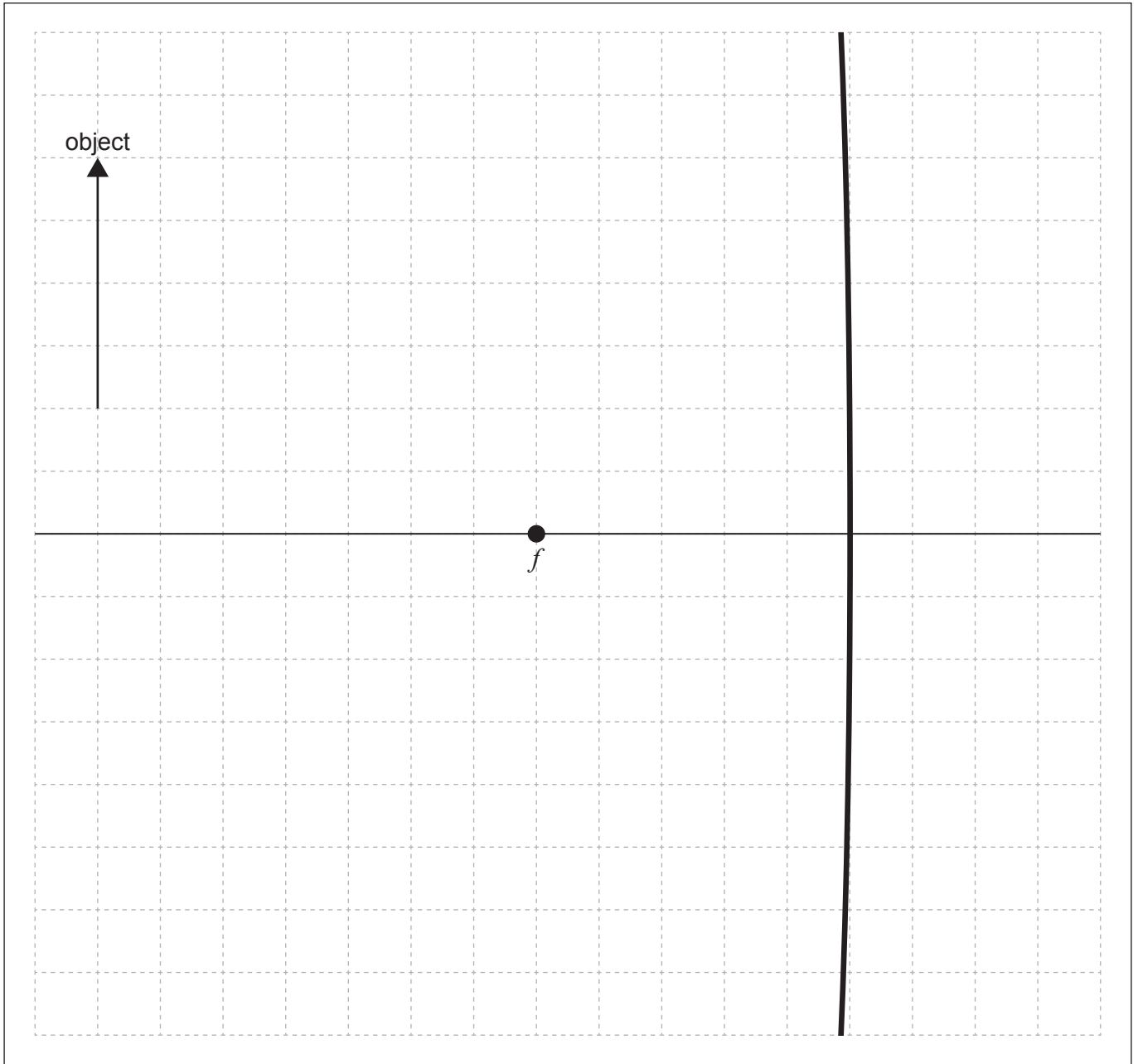
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**End of Option B**



**Option C — Imaging**

8. An object is placed in front of a concave mirror with the focal point  $f$  as shown.



- (a) Construct a ray diagram to locate the position of the image produced.

[2]

(Option C continues on the following page)



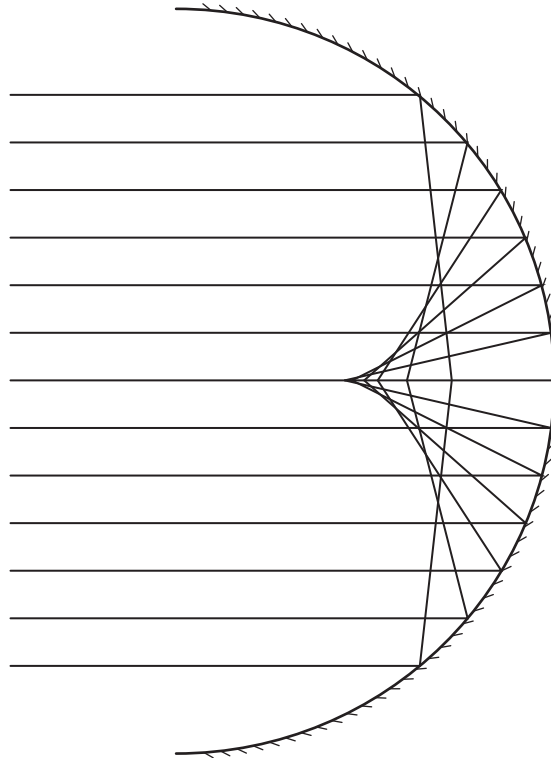
**(Option C, question 8 continued)**

(b) Describe the features of the image produced.

[1]

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(c) Parallel light rays are incident on a spherical concave mirror as shown.



State the problem illustrated by the diagram and how it is corrected in reflecting telescopes.

[2]

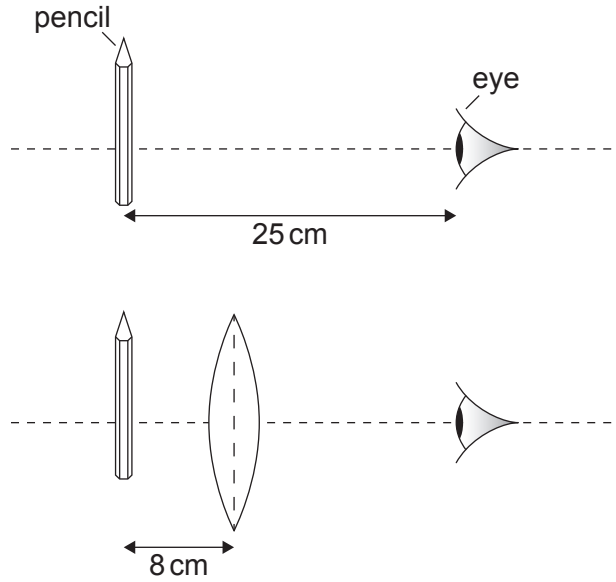
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**(Option C continues on the following page)**



(Option C continued)

9. The eye of an observer has a near point of 25 cm. A pencil is placed at the near point. A convex lens of focal length 8 cm is then placed between the pencil and the observer as shown. The pencil is positioned at the focal point of the lens.



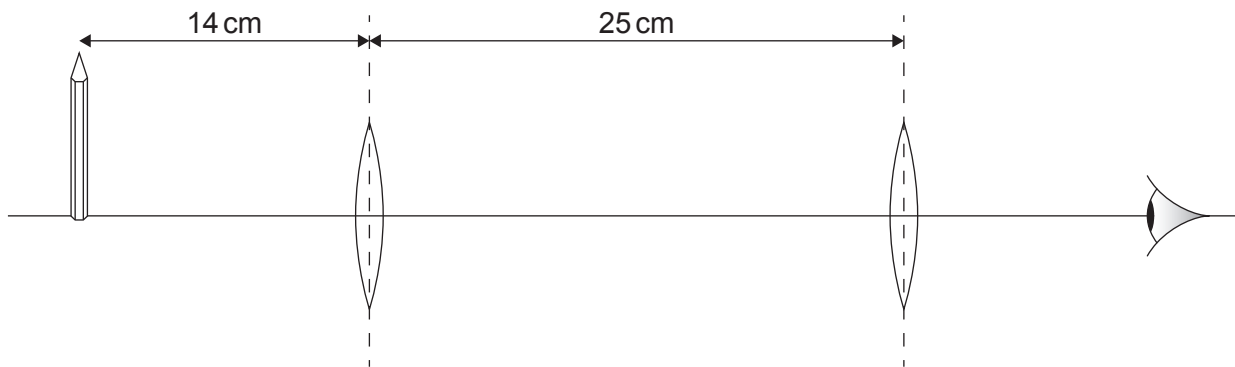
- (a) Determine the angular magnification of the lens when the image of the pencil is viewed at infinity.

[1]

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- (b) A student increases the magnification of the pencil by using two 8 cm focal length convex lenses placed 25 cm apart. The pencil is placed 14 cm from one of the lenses.



(Option C continues on the following page)



**(Option C, question 9 continued)**

- (i) Show that the magnitude of the magnification of the pencil produced by the lens closest to the pencil is approximately 1.3. [2]

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- (ii) Calculate the total magnification observed by the student using the two lenses as shown. [2]

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(c) The two 8 cm focal length convex lenses are now used to construct a telescope in normal adjustment. The diameter of the lenses is much greater than the diameter of the pupil of the eye. State, compared with the naked eye,

- (i) **one** advantage of using this telescope for astronomical observations. [1]

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- (ii) **one** disadvantage of using this telescope for astronomical observations. [1]

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**(Option C continues on page 23)**



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**(Option C, question 9 continued)**

- (d) Describe how international collaboration can improve the quality of the image of radio array telescopes.

[2]

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**(Option C continues on the following page)**



32EP23

**Turn over**



(Option C continued)

10. Signals in an optic fibre require amplification when intensity levels in the fibre have fallen to 1.5% of the original signal. A light signal of initial intensity  $I_0$  is sent down the optic fibre.

- (a) The fibre has an attenuation per unit length of  $0.30 \text{ dB km}^{-1}$ . Deduce that the length of the fibre is approximately 60 km before the signal requires amplification. [2]

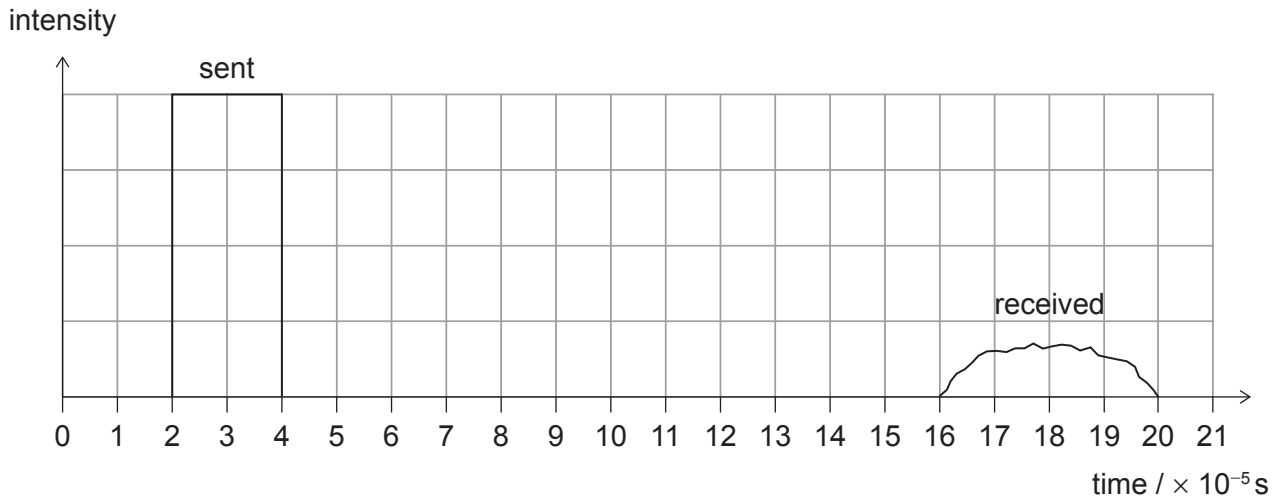
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A signal is sent down a 27 km step-index fibre and received according to the intensity–time graph below.



- (b) Calculate the refractive index of the fibre. [2]

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(Option C continues on the following page)



**(Option C, question 10 continued)**

(c) Discuss how using a graded-index fibre could reduce waveguide dispersion. [2]

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**End of Option C**



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**Turn over**

**Option D — Astrophysics**

11. (a) The Ghost of Jupiter is a nebula.

(i) Outline what is meant by a nebula. [1]

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(ii) Astrophysicists have deduced the nature of this nebula from Earth. Outline how they can make these deductions. [1]

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(b) Star X and star Y are in our own galaxy. They appear to move with respect to very distant stars when viewed from Earth during a six-month period. The following data are provided.

	<b>Parallax angle</b>	<b>Apparent brightness</b>
<b>Star X</b>	0.019 arc-second	$8.4 \times 10^{-9} \text{ W m}^2$
<b>Star Y</b>	0.038 arc-second	$3.1 \times 10^{-9} \text{ W m}^2$

(i) Deduce which star will appear to move more. [2]

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(ii) Calculate, in m, the distance to star X. [1]

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(Option D continues on the following page)



(Option D, question 11 continued)

(iii) Determine the ratio  $\frac{\text{luminosity of star X}}{\text{luminosity of star Y}}$ . [2]

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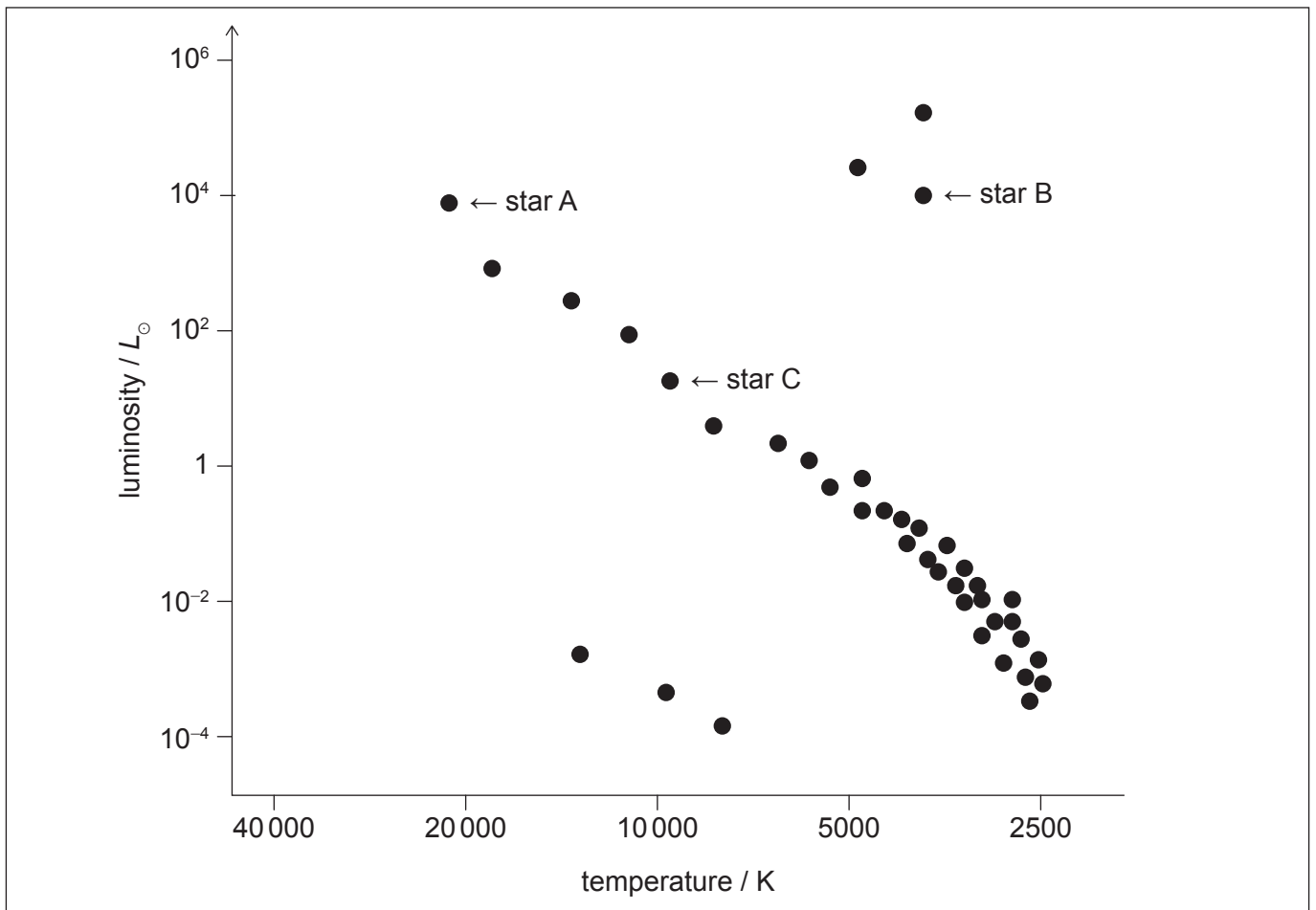
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(Option D continues on the following page)



(Option D continued)

12. Three stars A, B and C are labelled on the Hertzsprung–Russell (HR) diagram.  $L_{\odot}$  is the Luminosity of the sun.



- (a) State the main element that is undergoing nuclear fusion in star C. [1]

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- (b) Explain why star B has a greater surface area than star A. [2]

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(Option D continues on the following page)



**(Option D, question 12 continued)**

- (c) White dwarfs with similar volumes to each other are shown on the HR diagram.

Construct a line, on the HR diagram, to show the possible positions of other white dwarf stars with similar volumes to those marked on the HR diagram. [2]

- (d) Some stars on the HR diagram are likely to evolve into neutron stars.

Outline why the radius of a neutron star reaches a stable value. [2]

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**(Option D continues on the following page)**



**(Option D continued)**

**13.** Galaxy D has a redshift  $z = 0.13$ .

(a) Calculate, in Mpc, the distance to D using a Hubble constant value of  $73 \text{ km s}^{-1} \text{ Mpc}^{-1}$ . [2]

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(b) A Hubble constant value of  $73 \text{ km s}^{-1} \text{ Mpc}^{-1}$  gives an age of the universe to be  $13.4 \times 10^9$  years when assuming a constant rate of expansion has occurred.

(i) Determine in years, the age of the universe when the light detected on Earth now was originally emitted from D. [3]

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(ii) Evidence based on observations of type Ia supernovae affects the result in (b)(i). State the relevant conclusion from these observations. [1]

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**End of Option D**

**References:**

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