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Physics
Standard level
Paper 3

7 November 2024

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

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

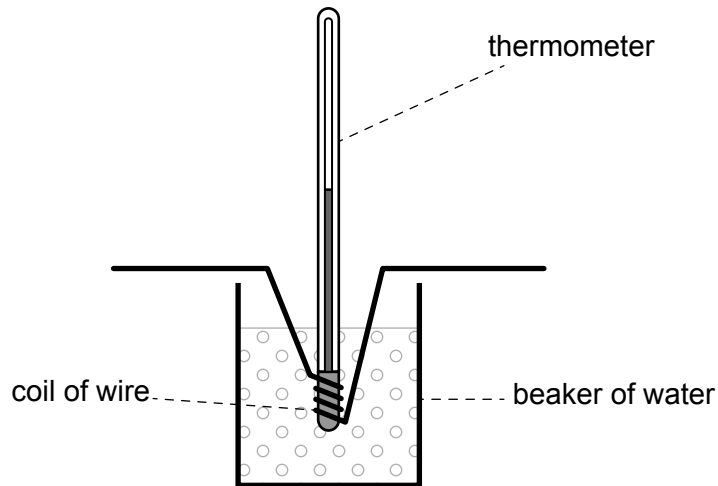
Section B	Questions
Answer all of the questions from one of the options.	
Option A — Relativity	3 – 5
Option B — Engineering physics	6 – 7
Option C — Imaging	8 – 10
Option D — Astrophysics	11 – 13



Section A

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

1. Two students investigate the variation with temperature θ of the resistance R of a copper wire. The plastic covered copper wire is wrapped around a mercury-in-glass thermometer and immersed in a beaker of water.



The students allow the water to cool slowly from 95 °C.

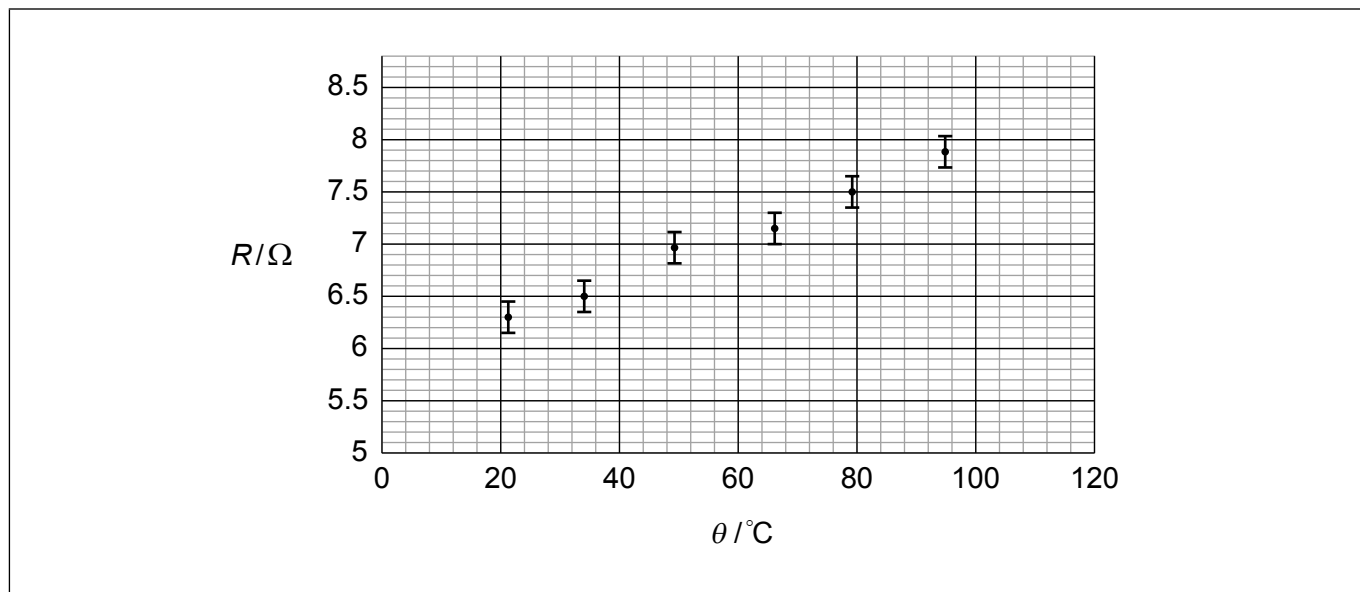
The students measure the resistance of the wire and the temperature of the water at the same instant.

(This question continues on the following page)



(Question 1 continued)

Their results are shown with error bars for R . Errors in θ can be ignored.



(a) The students suggest that R is given by $R = R_0 (1 + \alpha\theta)$.

(i) Draw a line of best fit for these data that is consistent with this equation. [1]

(ii) Calculate the gradient of your best-fit line. [2]

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(iii) Deduce α . State an appropriate unit for α . [4]

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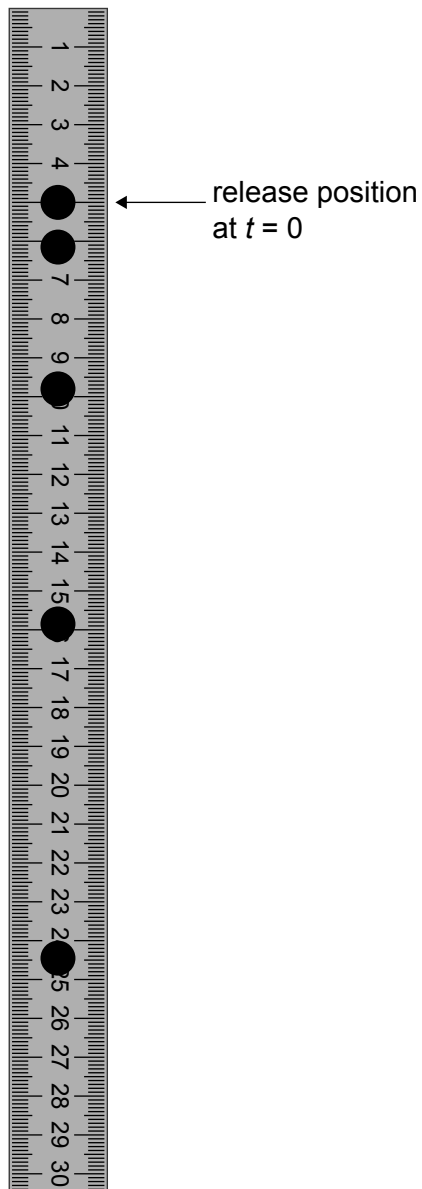
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2. A small ball is released from rest at time $t = 0$ in front of a vertical ruler. A multi-flash photograph is taken of the ball at $t = 0$ and every 0.050 s from then on.



(This question continues on the following page)



(Question 2 continued)

The distance s fallen by the ball is related to the acceleration g of the ball and t by $s = \frac{1}{2}gt^2$.

- (a) Determine g using the photograph. [3]

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- (b) The percentage uncertainty in t is $\pm 5\%$.
Estimate the absolute uncertainty in your value of g . [3]

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- (c) Suggest a suitable value for the maximum duration of the flash. [2]

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Answers written on this page
will not be marked.

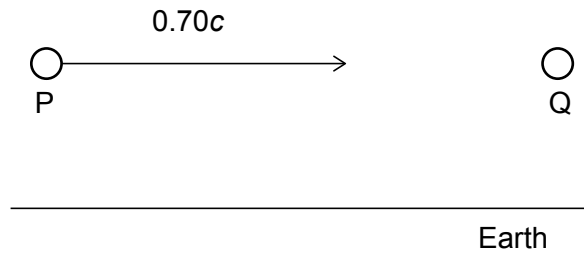


Section B

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

Option A — Relativity

- 3. P transmits a radio signal to Q. Relative to the Earth's surface, Q is stationary and P moves at a speed of $0.70c$ as shown.



- (a) State, using Galilean relativity, the speed of the radio signal relative to Q. [1]

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- (b) Determine, using relativistic velocity addition, the speed of the radio signal relative to Q. [2]

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- (c) A paradigm shift in science replaced Galilean relativity with the theory of special relativity. Explain how this paradigm shift was linked to Maxwell's discovery of a set of electromagnetic equations. [1]

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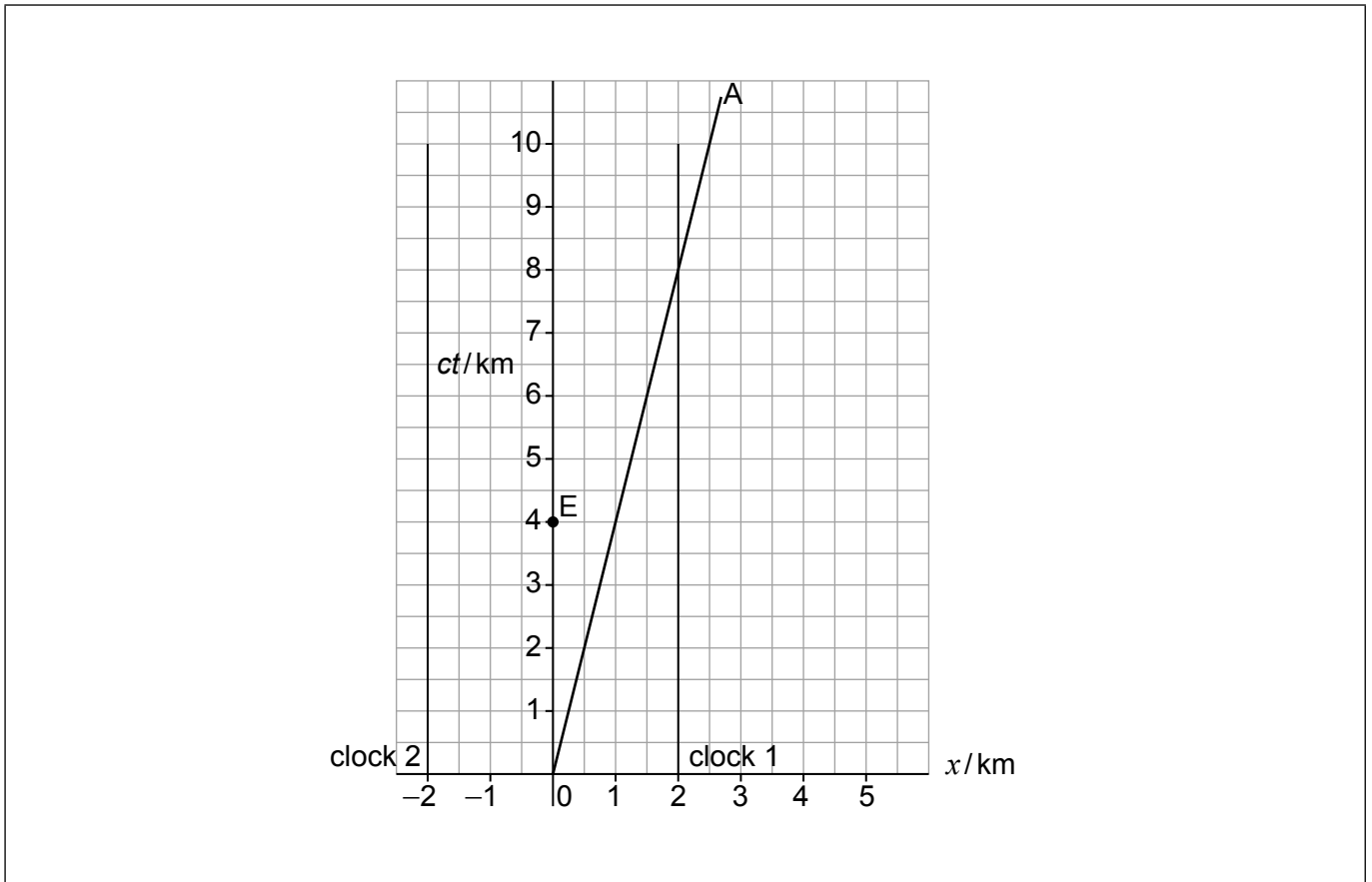
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(Option A continues on the following page)



(Option A continued)

4. The spacetime diagram (x, ct) for a space station S shows the worldlines of two clocks (clock 1 and clock 2). Each clock is 2.0 km from S. The spacetime diagram also shows the worldline of spaceship A.



(Option A continues on the following page)



(Option A, question 4 continued)

- (a) (i) Outline how clock 1 and clock 2 can be synchronized with a clock on S. [2]

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- (ii) Determine, in terms of c , the speed of A in the reference frame of S. [2]

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- (iii) Clock 1 and clock 2 emit separate light signals when A is at (0,0).

Identify, on the diagram, the proper time that elapses between the arrival of the light signals at A. [2]

- (b) At event E, spaceship P leaves S to intercept spaceship A. The speed of P is $0.50c$ in the reference frame of S.

- (i) Identify, with the letter X on the diagram, the event of P intercepting A. [1]

- (ii) State, in seconds, the time of event X for clock 2. [1]

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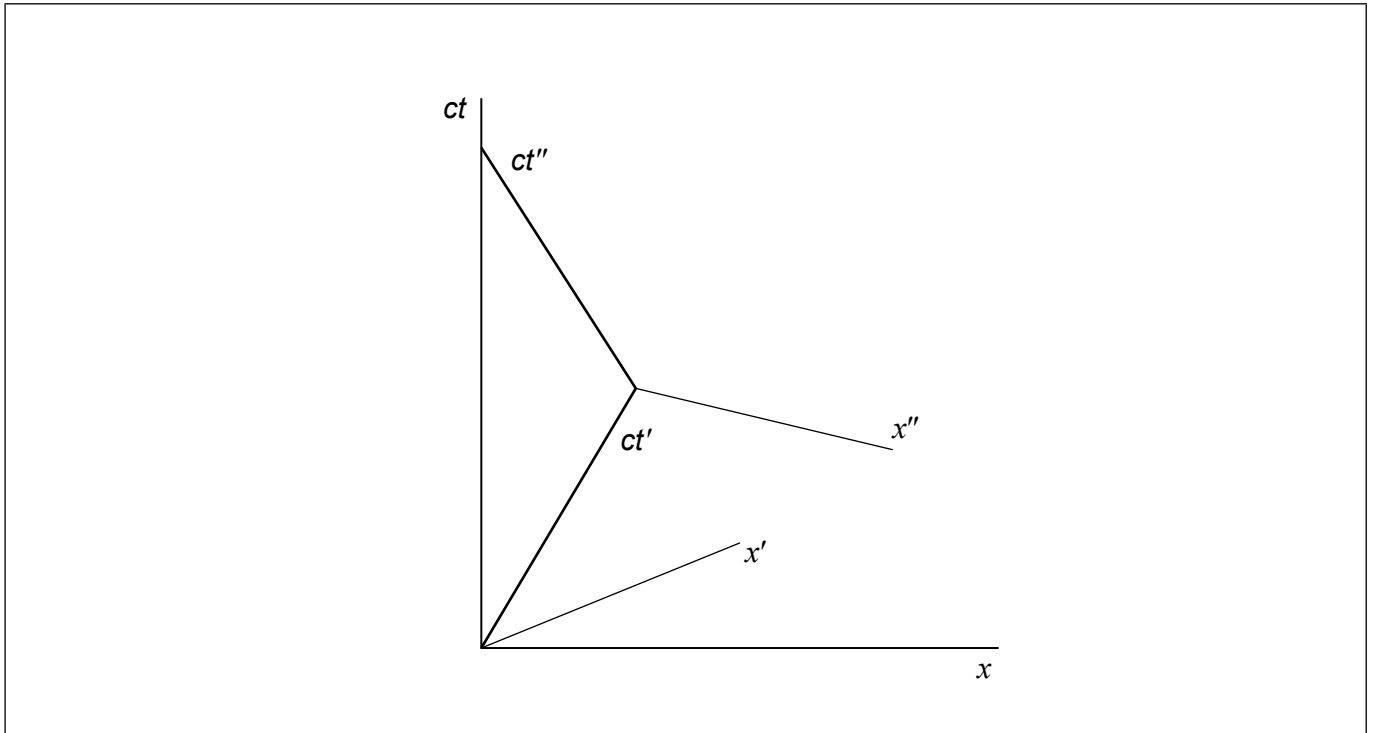
(Option A continues on the following page)



(Option A, question 4 continued)

(c) Spaceship A then returns to S.

The spacetime diagram shows the rest frame of A on its outward journey (x', ct') and on its return journey (x'', ct'').



An observer in A determines, for the **reference frame of S**, the time t_1 immediately before the change of velocity of A and the time t_2 immediately after the change of velocity of A.

- (i) Identify, with lines and labels on the spacetime diagram, the difference between t_1 and t_2 . [2]
- (ii) Explain how the difference between t_1 and t_2 arises. [1]

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(Option A continues on the following page)



(Option A continued)

5. Muons are formed in the Earth's atmosphere 2.5 km above the surface and then travel vertically downwards at a speed of $0.975c$. The mean lifetime of a muon is $2.2\ \mu\text{s}$ when measured in a frame in which the muon is at rest.

(a) Calculate the mean lifetime of the muon for the reference frame of the Earth. [2]

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(b) Muons are detected at the Earth's surface.

Explain, with supporting calculations, why this is evidence for time dilation. [3]

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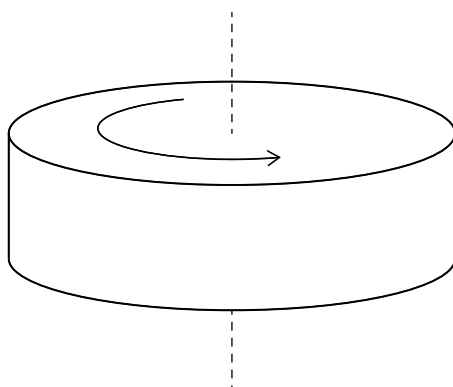
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End of Option A



Option B — Engineering physics

6. A flywheel is a rotating cylinder used to store rotational kinetic energy. Energy can be transferred from the flywheel as it slows down.



A flywheel used to store energy has a moment of inertia of 0.072 kg m^2 and a maximum angular speed of 8400 rad s^{-1} .

(Option B continues on the following page)



(Option B, question 6 continued)

(a) The rotational speed of the flywheel is reduced uniformly from the maximum speed to 3600 rad s^{-1} in a time of 9.6 s.

(i) Show that an average power of about 200 kW is transferred from the flywheel as its speed is reduced. [2]

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(ii) Calculate the torque acting on the flywheel as it decelerates. [2]

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(iii) Calculate the number of revolutions that the flywheel makes as it slows down. [2]

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(b) An engineer changes the flywheel design to increase the maximum energy that it can store.

Identify **two** factors that the engineer can change to do this. [2]

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(Option B continues on the following page)



(Option B continued)

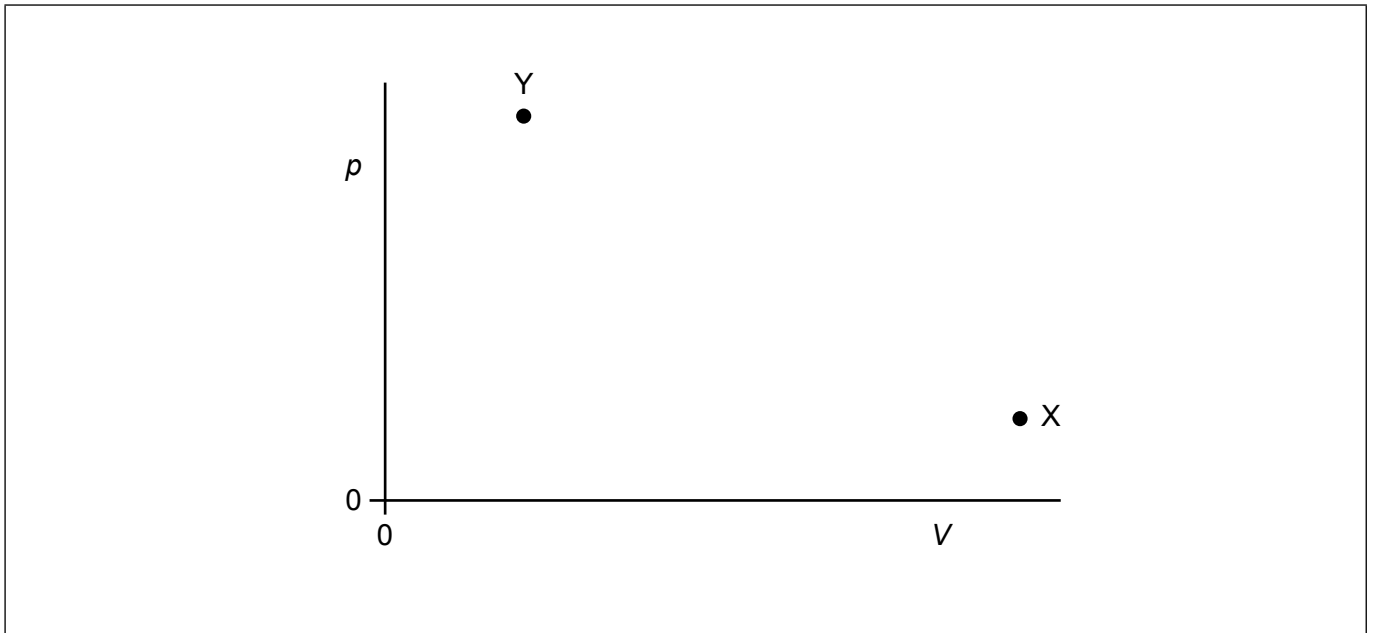
7. A fixed mass of an ideal gas is taken through a cycle that consists of three processes:

X → Y Isothermal compression from a pressure of 0.10 MPa and volume of $1.20 \times 10^{-3} \text{ m}^3$ to a pressure of 0.48 MPa

Y → Z Isobaric expansion

Z → X Adiabatic expansion to the initial state

(a) Draw, on the axes, the pV diagram for this cycle. X and Y are plotted for you. Numbers are not required on the axes. [2]



(b) Show that the volume of the gas at Y is $0.25 \times 10^{-3} \text{ m}^3$. [1]

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(Option B continues on the following page)



(Option B, question 7 continued)

(c) An algebraic statement of the first law of thermodynamics is $Q = \Delta U + W$.

Data for the cycle are provided in the table.

Process	Q / J	$\Delta U / J$	W / J
$X \rightarrow Y$			-188
$Y \rightarrow Z$	+262		+105
$Z \rightarrow X$			+157
whole cycle			+74

(i) Complete the table. Use the answer box below for your calculations. [3]

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(ii) Determine the volume of the gas at Z. [2]

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(iii) Determine the efficiency of this cycle. [2]

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(Option B continues on the following page)



(Question 7 continued)

(d) Outline why this theoretical cycle is unsuitable for use in a practical heat engine. [2]

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End of Option B



Option C — Imaging

8. A real image, four times larger than the object, is formed 0.40 m from a converging lens.

(a) Calculate the focal length of the lens.

[3]

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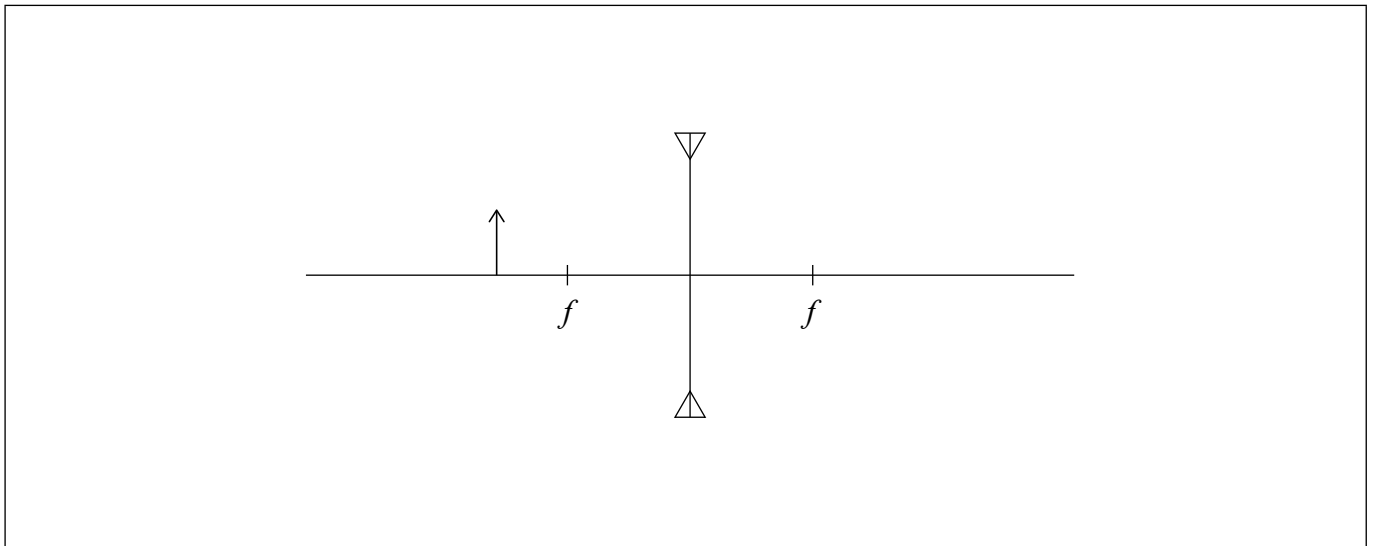
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(b) The converging lens is replaced by a diverging lens of focal length f . The position of the object is shown.



Determine, using a ray diagram, the nature of the image formed.

[2]

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(Option C continues on the following page)



(Option C continued)

9. (a) (i) Identify the optical components in an astronomical reflecting telescope with Newtonian mounting.

[2]

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- (ii) Explain **one** advantage that an astronomical reflecting telescope with a Cassegrain mounting has over one with a Newtonian mounting.

[1]

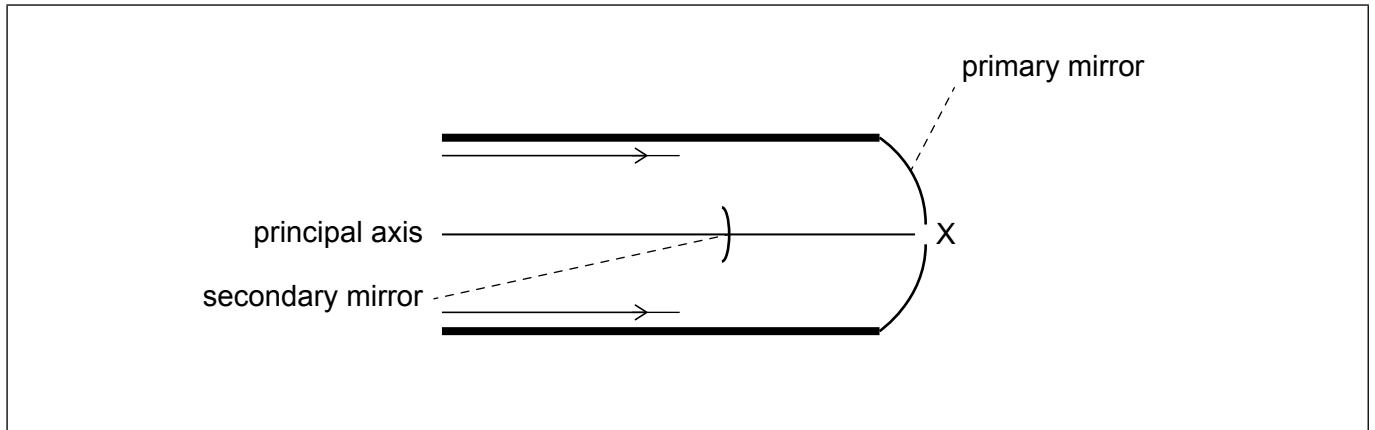
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(Option C continues on the following page)



(Option C, question 9 continued)

- (b) In a reflecting telescope with a Cassegrain mounting, the primary mirror has a focal length of 8.0m. The telescope is used to view a feature on the Moon that subtends an angle of 2.5 mrad at the axis of the primary mirror.



- (i) Calculate the height of the image formed by the primary mirror. [1]

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- (ii) The initial paths of two rays parallel to the principal axis are shown on the diagram. Show, by completing the paths of these rays, the formation of the final image at X. [2]
- (iii) The secondary mirror is 4.5 m from X. Calculate the focal length of the secondary mirror. [2]

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(Option C continues on the following page)



(Option C continued)

10. Light propagates along an optic fibre that has a core of refractive index 1.59 and a cladding of refractive index 1.48.

(a) Show that the critical angle at the core-cladding boundary is approximately 70° . [2]

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(b) A ray enters the optic fibre from the air through a core surface that is at 90° to the axis of the fibre.



(i) Determine the largest angle of incidence I that this ray can have in the air for total internal reflection to occur at the core-cladding boundary. [2]

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(ii) Describe what happens to rays of light with angles of incidence greater than I . [1]

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(Option C continues on the following page)



(Option C, question 10 continued)

- (c) The attenuation per unit length in the core material is 5.5 dB km^{-1} .

Estimate the length of the optic fibre that will reduce the brightness of light by a factor of 10^6 .

[2]

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End of Option C



Option D — Astrophysics

11. (a) Outline the differences between open stellar clusters and globular stellar clusters. [2]

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(b) Discuss how Cepheid variable stars are used for distance determinations in astronomy. [3]

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(c) Galactic dust absorbs light.

Predict the effect that galactic dust has on the estimate of the distance to a Cepheid variable star.

[2]

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(Option D continues on the following page)



(Option D continued)

12. Data for the main-sequence star 10 Lacertae are provided. T_{\odot} and L_{\odot} refer to the temperature of the Sun and to the luminosity of the Sun.

$$\text{surface temperature of 10 Lacertae} = 6.3 T_{\odot}$$

$$\text{luminosity of 10 Lacertae} = 100\,000 L_{\odot}$$

(a) Calculate $\frac{\text{radius of 10 Lacertae}}{\text{radius of the Sun}}$. [3]

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(b) Show that the mass of 10 Lacertae is about 30 times the mass of the Sun. [2]

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(c) Outline, with reference to its mass, the likely final state of 10 Lacertae. [2]

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(Option D continues on the following page)



(Option D continued)

13. The galaxy NGC 6251 is 350 Mly from Earth and has a redshift of 0.025.

(a) Show that the NGC 6251 data lead to an estimate for the Hubble constant of about $70 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

[3]

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(b) (i) Estimate, using your answer to (a), the age of the universe in seconds.

[2]

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(ii) State the assumption you made in your estimate for (b)(i).

[1]

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End of Option D

