Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Standard level
Paper 3

2 May 2023

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

Candidate session number

1 hour

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 – 9
Option D — Astrophysics	10 – 13

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29 pages

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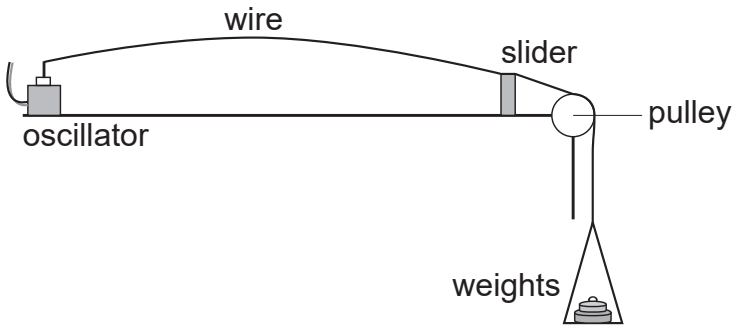
will not be marked.

Section A

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

1. A student attaches one end of a copper wire to an oscillator operating at a fixed frequency. The other end of the wire passes over a pulley to weights that hang vertically. The first harmonic standing wave is established by using the slider to change the length of the wire. The procedure is repeated for different weights.



The mass m of the weights and the wavelength λ of the wave are related by

$$m = \frac{\mu f^2}{g}\lambda^2$$

where μ is a constant, f is the frequency of the wave and $g = 9.8\,\text{ms}^{-2}$.

(a) Deduce the unit of μ in terms of fundamental SI units. [1]

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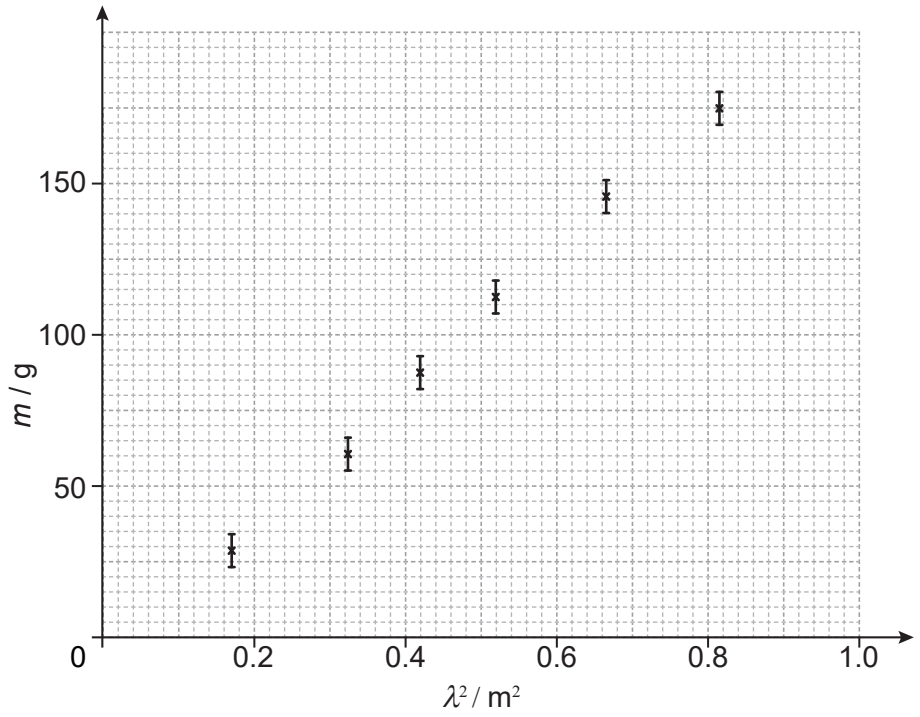
(This question continues on the following page)

(Question 1 continued)

(b) The graph shows the data obtained by the student, plotted to show the variation of m with λ^2.



(i) Draw the line of best fit for these data. [1]

(ii) Identify the evidence for a systematic error in the data. [1]

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(iii) Suggest a possible reason for the systematic error. [1]

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(This question continues on the following page)

(Question 1 continued)

(iv) Calculate the gradient of the graph. [2]

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(c) The percentage uncertainty of the gradient is 6.0 %. The frequency f of the wave is $(60.0 \pm 2.0\,\%)$ Hz.

Estimate, using the answer to (b)(iv), μ for the string. Include the percentage uncertainty of μ in your answer. [2]

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2. A student wants to verify the relation $T = 2\pi\sqrt{\frac{L}{g}}$ between the period T of a simple pendulum and the length L of the pendulum, where g is the acceleration of free fall. The student operates a stopwatch to measure one oscillation and a millimeter ruler to measure the length of the pendulum.

(a) State, for this experiment,

(i) one variable that must be controlled, [1]

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(ii) the main source of error in T. [1]

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(b) To determine T more precisely, the student measures the total time for 20 oscillations and divides by 20.

Suggest why this is preferable to measuring the time for just one oscillation. [2]

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(This question continues on the following page)

(Question 2 continued)

(c) (i) The student plots a graph with L on the horizontal axis. State the variable that must be plotted on the vertical axis in order to obtain a line of best fit that is straight. [1]

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(ii) Calculations using the data of the experiment show that $g = 9.71622\,\text{m}\,\text{s}^{-2}$ with a percentage uncertainty of 8 %. Determine the value of g that can be obtained from this experiment. Include the absolute uncertainty in g to one significant figure. [2]

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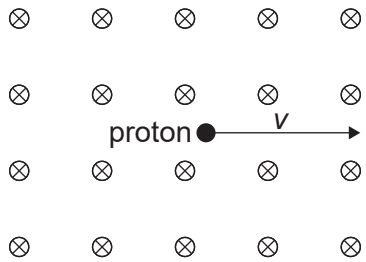
Section B

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

Option A — Relativity

3. A proton is moving in a region of magnetic field of strength *B*. The speed of the proton relative to the magnetic field is *v*.



In the reference frame in which the magnetic field is at rest, the proton experiences an initial magnetic force *evB* upwards.

(a) Outline why there can be no magnetic force on the proton in the proton's rest frame. [1]

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(b) Discuss the nature of the force in the proton's rest frame. [2]

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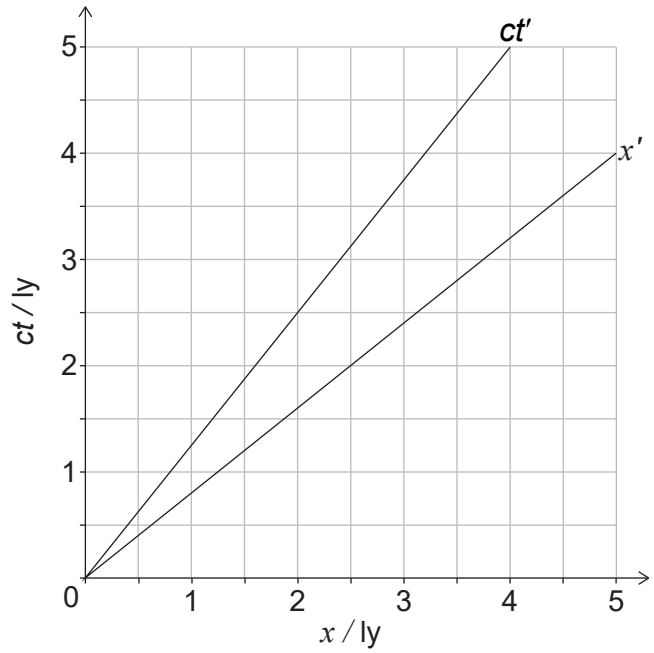
(Option A continues on the following page)

(Option A continued)

4. The diagram shows the axes of a coordinate system S at rest relative to the Earth. Earth is at the origin of S.



x' and ct' are the coordinates of a reference frame S′ in which a spacecraft is at rest. When the origins of the two sets of axes coincide, all clocks in the frames show zero.

(a) Show that the speed of the spacecraft is 0.80c as measured in S. [1]

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(Option A continues on the following page)

(Option A, question 4 continued)

(b) (i) An event has coordinates $x = 0$ and $ct = 0.60\,\text{ly}$ in S. Show, using a Lorentz transformation, that the time coordinate of this event in S′ is $ct' = 1.00\,\text{ly}$. [2]

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(ii) Label, on the diagram with the letter P, the point on the ct' axis whose ct' coordinate is 1.00 ly. [2]

(c) At $ct = 0$, a light beam is sent from Earth to a space station at rest 4.0 ly away in S. Event R is the arrival of the light beam at the space station.

(i) Draw lines to indicate R on the diagram. [2]

(ii) Determine, using the diagram or otherwise, the space coordinate x' of event R in S′. [2]

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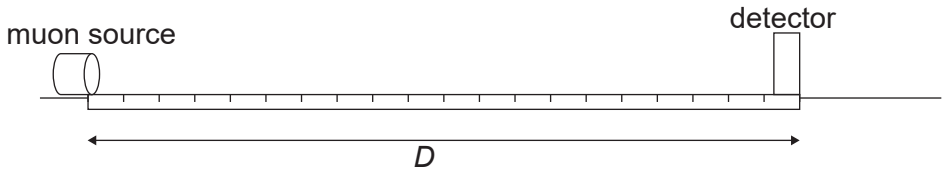
(Option A continues on the following page)

(Option A continued)

5. A muon is an unstable particle with a half-life of 1.56 μs as measured in the muon's rest frame. Muons are produced in a laboratory and are all directed at a speed 0.866*c* towards a muon detector. The gamma factor (γ) for this speed is 2.00. The detector, according to observers in the laboratory, is a distance *D* from the muon source.



(a) According to laboratory observers $\frac{\text{number of muons detected}}{\text{number of muons produced}} = \frac{1}{2}$.

Calculate *D*. [2]

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(b) In the muon source rest frame (frame S), the detector is approaching at a speed 0.866*c*.

In frame S,

(i) show that the distance travelled by the detector when it meets the muon source is 405 m. [1]

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(ii) determine the time taken for the detector to reach the muon source. [1]

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(Option A continues on the following page)

(Option A, question 5 continued)

(c) Calculate, using the answers to (b)(i) and (b)(ii) the ratio $\frac{\text{number of muons detected}}{\text{number of muons produced}}$ in S. [2]

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(d) Comment on the ratios in (a) and (c). [2]

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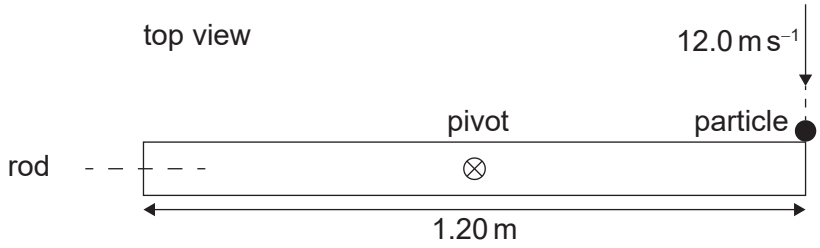
End of Option A

Option B — Engineering physics

6. A uniform rod of length 1.20 m is at rest on a horizontal surface. The rod is pivoted at its centre so that it is free to rotate about a vertical axis through the centre.



A particle of mass 0.200 kg moving with speed 12.0 m s^{-1} collides with and sticks to one end of the rod.

(a) The moment of inertia of the rod about the axis is 0.180 kg m^2. Show that the moment of inertia of the rod–particle system is about 0.25 kg m^2. [1]

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(b) Show that the angular speed of the system immediately after the collision is about 5.7 rad s^{-1}. [2]

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(c) Calculate the energy lost during the collision. [2]

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(Option B continues on the following page)

(Option B, question 6 continued)

(d) A frictional torque of magnitude 0.152 N m acts on the system just after it begins to rotate. Calculate

(i) the angular deceleration of the rod. [1]

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(ii) the number of revolutions made by the rod until it stops rotating. [2]

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(e) In another situation the rod rests on a horizontal frictionless surface with no pivot. Predict, without calculation, the motion of the rod–particle system after the collision. [2]

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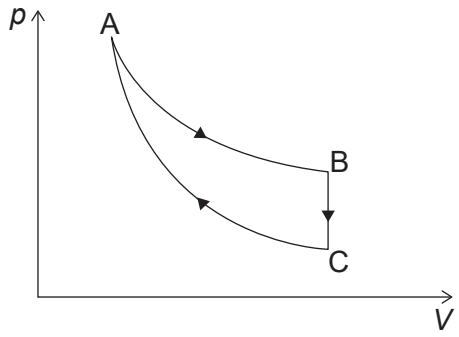
(Option B continues on the following page)

(Option B continued)

7. The *pV* diagram shows a heat engine cycle consisting of adiabatic, isothermal and isovolumetric parts. The working substance of the engine is an ideal gas.



The following data are available:

$p_A = 5.00 \times 10^5\,\text{Pa}$

$V_A = 2.00 \times 10^{-3}\,\text{m}^3$

$T_A = 602\,\text{K}$

$p_B = 3.00 \times 10^4\,\text{Pa}$

$p_C = 4.60 \times 10^3\,\text{Pa}$

(a) Suggest why AC is the adiabatic part of the cycle. [2]

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(b) Show that the volume at C is $3.33 \times 10^{-2}\,\text{m}^3$. [2]

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(Option B continues on the following page)

(Option B, question 7 continued)

(c) Suggest, for the change A ⇒ B, whether the entropy of the gas is increasing, decreasing or constant. [2]

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(d) Calculate the thermal energy (heat) taken out of the gas from B to C. [2]

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(e) The highest and lowest temperatures of the gas during the cycle are 602 K and 92 K.

The efficiency of this engine is about 0.6. Outline how these data are consistent with the second law of thermodynamics. [2]

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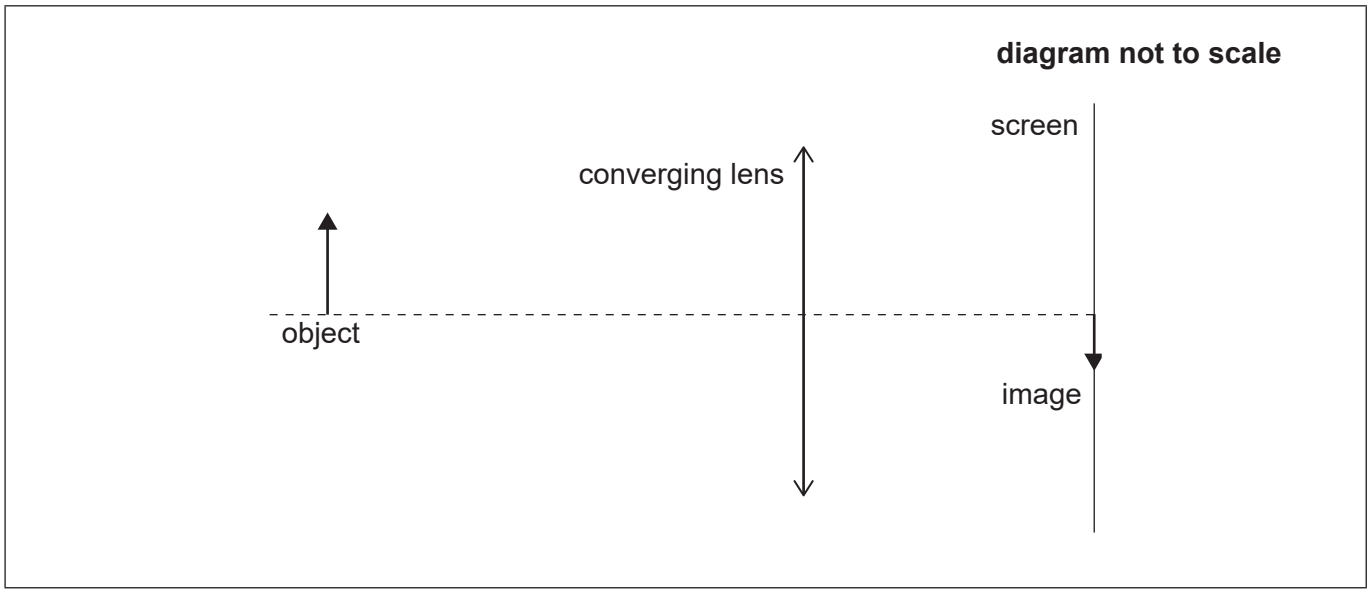
End of Option B

Option C — Imaging

8. A converging lens is placed between an object and a screen. An image of the object is formed on the screen.



(a) Draw a ray to locate the focal point of the lens. Label this point with the letter F. [1]

(b) The focal length of the lens is 4.0 cm and the height of the image is half the height of the object. Determine the distance of the object from the lens. [3]

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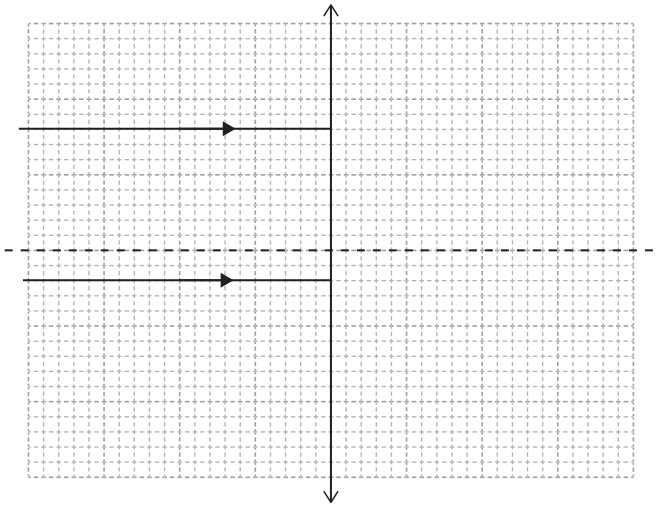
(Option C continues on the following page)

(Option C, question 8 continued)

(c) The lens suffers from spherical aberration.

(i) Draw lines to complete the rays in the diagram. [1]



(ii) Describe the effect of spherical aberration on the image formed by the lens. [1]

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(iii) State how spherical aberration may be corrected. [1]

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(Option C continues on page 21)

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(Option C, question 8 continued)

(d) A simple optical astronomical refracting telescope consists of an objective lens of focal length 75 cm and an eyepiece of focal length 4.0 cm. The telescope is used to view the Moon. The Moon subtends an angle of 0.51° at the unaided eye.

(i) Calculate the angle subtended by the Moon when viewed through the telescope. [2]

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(ii) The telescope is now turned around so that the eye of the observer is behind the objective lens. State the change, if any, in the image of the Moon. [1]

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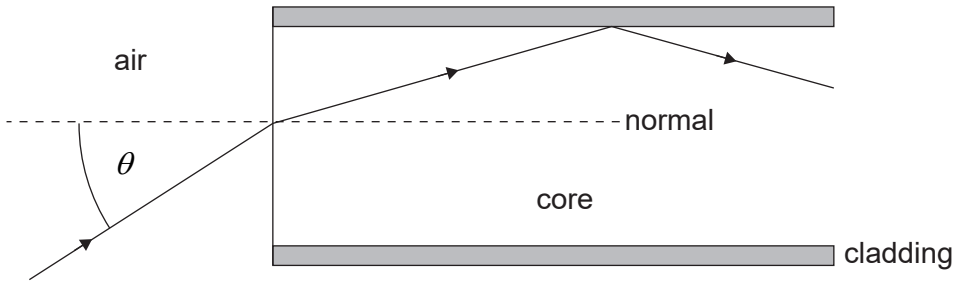
(Option C continues on the following page)

(Option C continued)

9. A ray of monochromatic light is incident on an optical fibre making an angle of θ with the normal. The refractive index of the core is 1.500 and the refractive index of the cladding is 1.489.



(a) (i) Calculate the critical angle θ_c at the core-cladding boundary. [2]

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(ii) Determine the maximum value of θ such that the ray is incident on the core-cladding boundary at an angle greater than the critical angle. [2]

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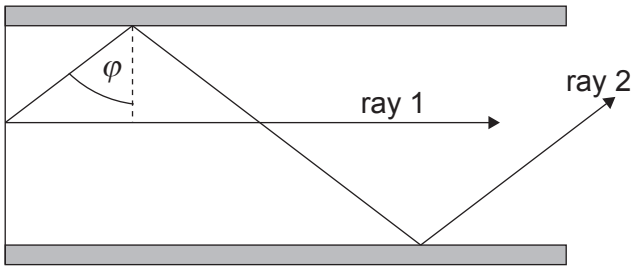
(Option C continues on the following page)

(Option C, question 9 continued)

(b) The diagram shows two rays following different paths in the optical fibre. Ray 1 travels along the axis of the fibre. Ray 2 is incident on the core-cladding boundary at an angle φ just greater than θ_c.



The length of the optical fibre is 1 km. Show that the time delay between the arrival of the two rays at the end of the optical fibre is about 37 ns. [3]

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(Option C continues on page 25)

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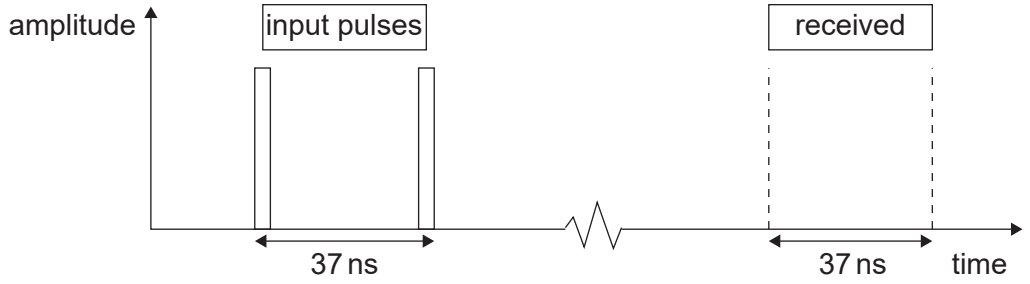
(Option C, question 9 continued)

(c) A signal transmitted by the optical fibre consists of very narrow digital pulses. The pulses are 37 ns apart. The graph shows the variation with time of the amplitude of two consecutive pulses input to the optical fibre.

(i) Sketch, on the axes, the variation with time of the amplitude of the two pulses after they have travelled by all possible ray paths along a 1 km length of the optical fibre. [2]



(ii) State what would happen when the input pulses are separated by less than 37 ns. [1]

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End of Option C

Option D — Astrophysics

10. Distinguish between open stellar clusters and globular stellar clusters. [1]

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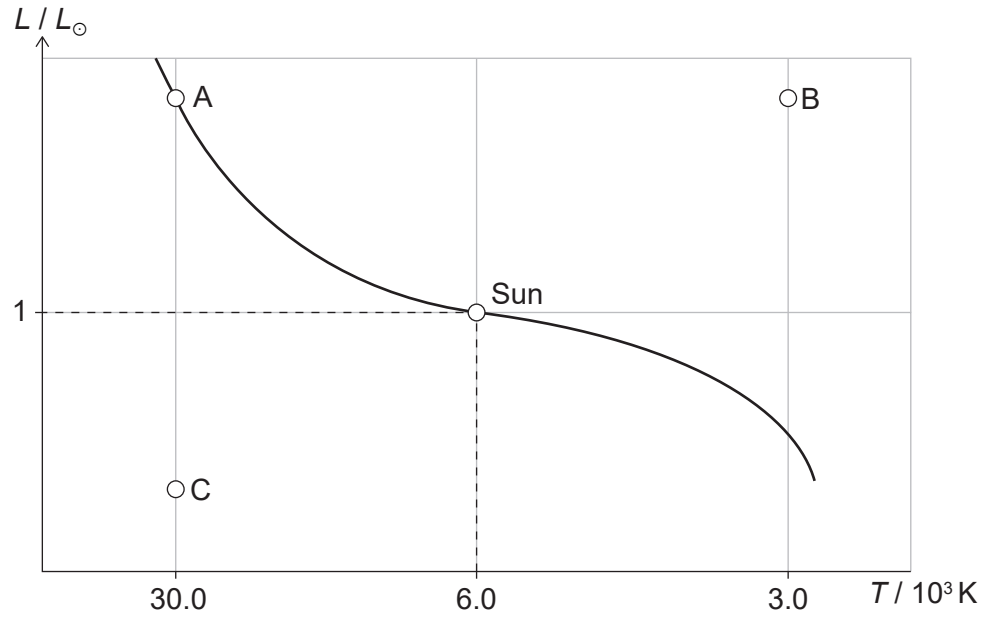
11. The graph shows an incomplete Hertzsprung–Russell (HR) diagram. The position of the Sun and three other stars, A, B and C, are shown.



$M_\odot$, $R_\odot$ and $L_\odot$ are the mass, radius and luminosity of the Sun.

(a) The mass of star A is $52\,M_\odot$. Show that the luminosity of star A is about $10^6\,L_\odot$. [1]

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(Option D continues on the following page)

(Option D, question 11 continued)

(b) Determine the radius of star B in terms of $R_{\odot}$. [3]

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(c) Describe the main stages in the evolution of star A after leaving the main sequence. [3]

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(d) The luminosity of star C is $2.4 \times 10^{23}\,\text{W}$ and its apparent brightness is $4.1 \times 10^{-14}\,\text{W m}^{-2}$. Determine the distance, in pc, to star C. [2]

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(e) Suggest whether the method of stellar parallax can be used to measure the distance to star C. [1]

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(Option D continues on the following page)

(Option D continued)

12. A distant galaxy emits light of wavelength 486 nm. The light received on Earth has wavelength 512 nm.

(a) Determine the recession speed of the galaxy. [2]

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(b) Estimate the distance to the galaxy in pc. Take the Hubble constant as $72\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. [1]

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(c) Astrophysicists continue to seek an accurate value of the Hubble constant. State the importance of this constant for cosmology. [1]

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(Option D continues on the following page)

(Option D continued)

13. (a) Describe how the existence of the cosmic microwave background (CMB) radiation is evidence of a Hot Big Bang. [3]

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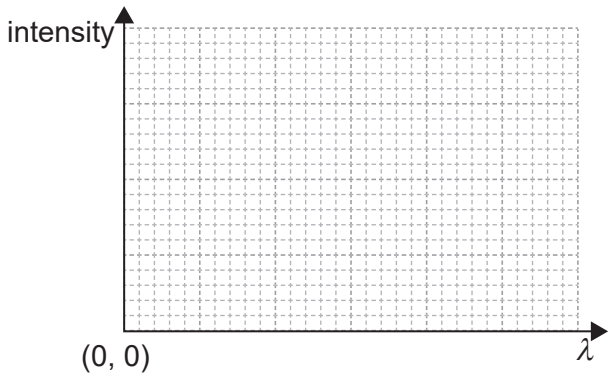
(b) (i) Draw, on the axes, a graph to show the variation of the intensity of the CMB with wavelength λ. [1]



(ii) Suggest how your graph can be used to estimate the temperature of the CMB. [1]

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End of Option D

References:

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