Diploma Programme
Programme du diplôme
Programa del Diploma

M19/4/PHYSI/SP3/ENG/TZ1/XX

Diploma Programme
Programme du diplôme
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Physics
Standard level
Paper 3

Monday 20 May 2019 (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 – 10
Option D — Astrophysics	11 – 12

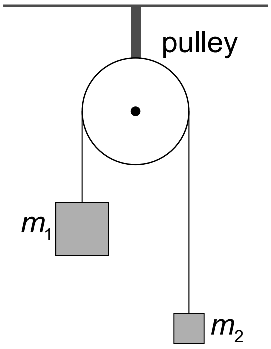
21 pages

2219 – 6512

Section A

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

1. In an experiment to measure the acceleration of free fall a student ties two different blocks of masses m_1 and m_2 to the ends of a string that passes over a frictionless pulley.



The student calculates the acceleration a of the blocks by measuring the time taken by the heavier mass to fall through a given distance. Their theory predicts that $a = g\frac{m_1 - m_2}{m_1 + m_2}$ and this can be re-arranged to give $g = a\frac{m_1 + m_2}{m_1 - m_2}$.

(a) In a particular experiment the student calculates that $a = (0.204 \pm 0.002)\,\text{m s}^{-2}$ using $m_1 = (0.125 \pm 0.001)\,\text{kg}$ and $m_2 = (0.120 \pm 0.001)\,\text{kg}$.

(i) Calculate the percentage error in the measured value of g. [3]

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(ii) Deduce the value of g and its absolute uncertainty for this experiment. [2]

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(This question continues on the following page)

(Question 1 continued)

(b) There is an advantage and a disadvantage in using two masses that are almost equal.

State and explain,

(i) the advantage with reference to the magnitude of the acceleration that is obtained. [2]

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(ii) the disadvantage with reference to your answer to (a)(ii). [2]

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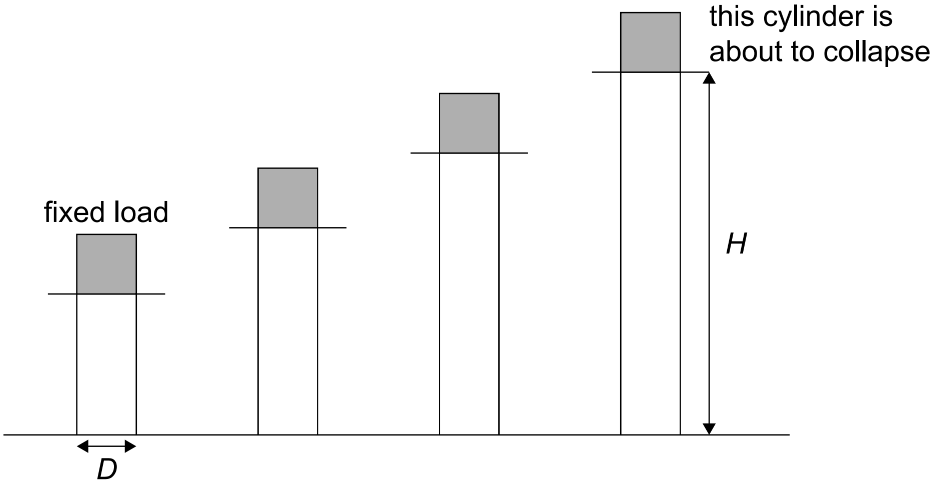
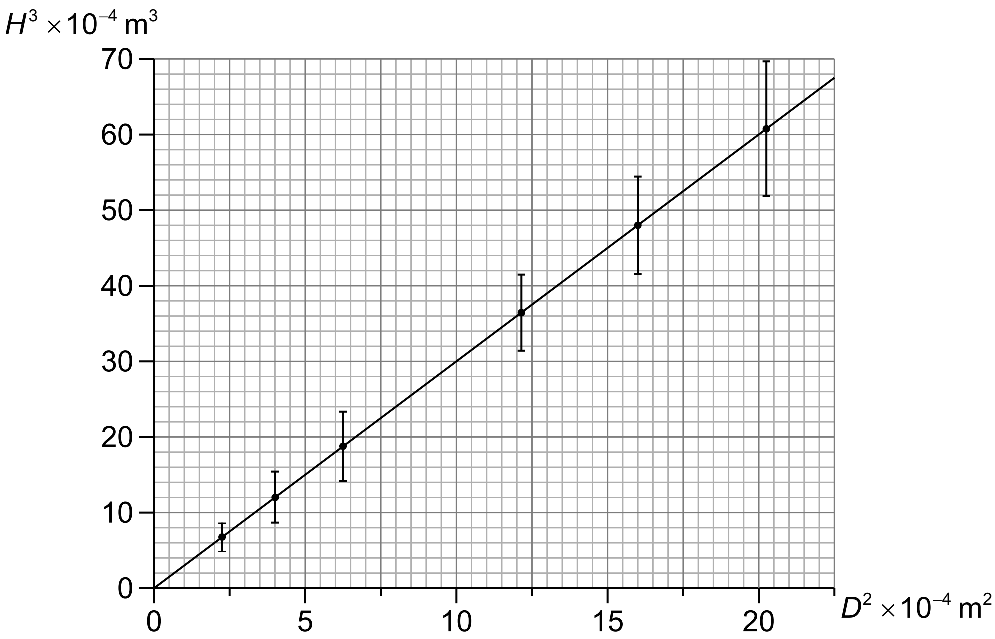
2. In an investigation a student folds paper into cylinders of the same diameter D but different heights. Beginning with the shortest cylinder they applied the same fixed load to each of the cylinders one by one. They recorded the height H of the first cylinder to collapse.



They then repeat this process with cylinders of different diameters.

The graph shows the data plotted by the student and the line of best fit.



Theory predicts that $H = cD^{\frac{2}{3}}$ where c is a constant.

(This question continues on the following page)

(Question 2 continued)

(a) Suggest why the student's data supports the theoretical prediction. [2]

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(b) Determine *c*. State an appropriate unit for *c*. [3]

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(c) Identify **one** factor that determines the value of *c*. [1]

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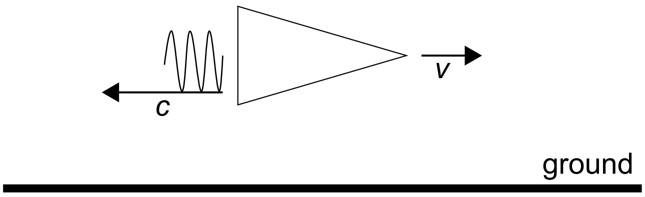
Section B

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

Option A — Relativity

3. A rocket moving with speed *v* relative to the ground emits a flash of light in the backward direction.



An observer in the rocket measures the speed of the flash of light to be *c*.

State the **speed** of the flash of light according to an observer on the ground using

(a) Galilean relativity. [1]

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(b) Maxwell's theory of electromagnetism. [1]

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(c) Einstein's theory of relativity. [1]

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(Option A continues on the following page)

(Option A continued)

4. Muons are created at a height of 3230 m above the Earth's surface. The muons move vertically downward at a speed of 0.980 *c* relative to the Earth's surface. The gamma factor for this speed is 5.00. The half-life of a muon in its rest frame is 2.20 μs.

(a) Estimate in the Earth frame the fraction of the original muons that will reach the Earth's surface before decaying according to

(i) Newtonian mechanics. [3]

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(ii) special relativity. [2]

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(b) Demonstrate how an observer moving with the same velocity as the muons accounts for the answer to (a)(ii). [2]

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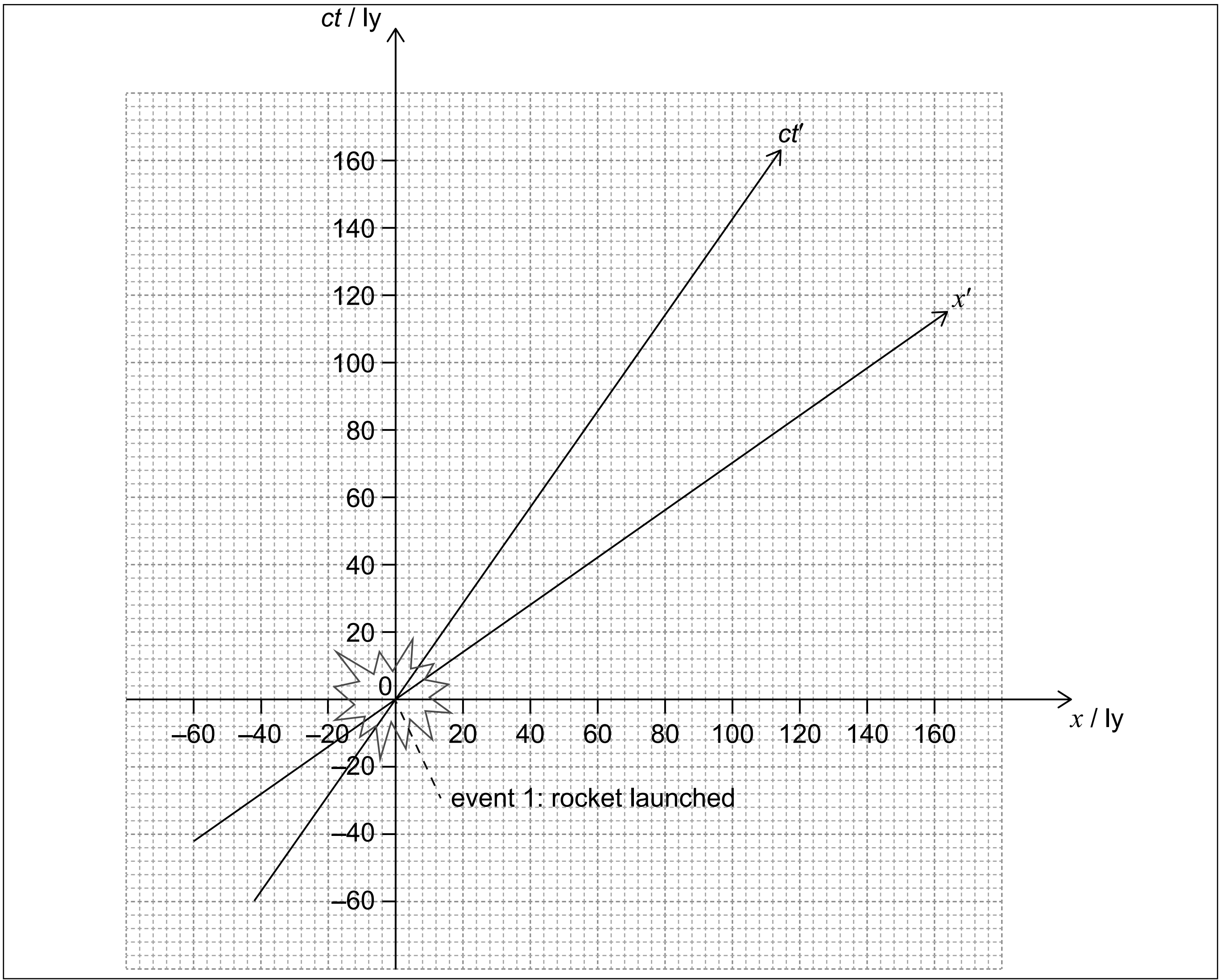
(Option A continues on the following page)

(Option A continued)

5. The diagram shows space and time axes x and *ct* for an observer at rest with respect to a galaxy. A spacecraft moving through the galaxy has space and time axes x' and ct'.



A rocket is launched towards the right from the spacecraft when it is at the origin of the axes. This is labelled event 1 on the spacetime diagram. Event 2 is an asteroid exploding at $x = 100$ ly and $ct = 20$ ly.

(a) Plot, on the axes, the point corresponding to event 2. [1]

(b) Suggest whether the rocket launched by the spacecraft might be the cause of the explosion of the asteroid. [2]

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(Option A continues on the following page)

(Option A, question 5 continued)

(c) Show that the value of the invariant spacetime interval between events 1 and 2 is 9600 ly^2. [1]

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(d) (i) An observer in the spacecraft measures that events 1 and 2 are a distance of 120 ly apart. Determine, according to the spacecraft observer, the time between events 1 and 2. [2]

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(ii) Using the spacetime diagram, determine which event occurred first for the spacecraft observer, event 1 or event 2. [2]

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(e) Determine, using the diagram, the speed of the spacecraft relative to the galaxy. [2]

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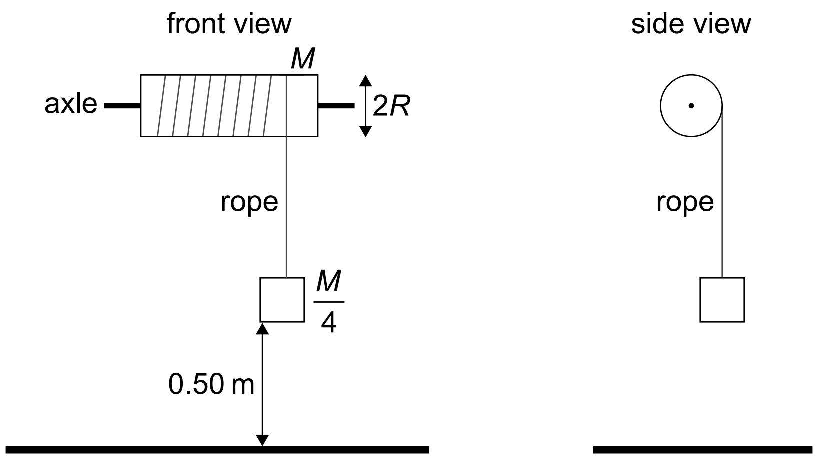
End of Option A

Option B — Engineering physics

6. A solid cylinder of mass M and radius R is free to rotate about a fixed horizontal axle. A rope is tied around the cylinder and a block of mass $\frac{M}{4}$ is attached to the end of the rope.

diagram not to scale



The system is initially at rest and the block is released. The moment of inertia of the cylinder about the axle is $\frac{1}{2}MR^2$.

(a) Show that

(i) the angular acceleration α of the cylinder is $\frac{g}{3R}$ [3]

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(ii) the tension T in the string is $\frac{Mg}{6}$. [1]

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(Option B continues on the following page)

(Option B, question 6 continued)

(b) The block falls a distance 0.50 m after its release before hitting the ground. Show that the block hits the ground 0.55 s after release. [2]

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(c) The following data are available:

$$R = 0.20\,\text{m}$$

$$M = 12\,\text{kg}$$

Calculate, for the cylinder, at the instant just before the block hits the ground

(i) the angular momentum. [2]

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(ii) the kinetic energy. [2]

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(Option B continues on the following page)

(Option B continued)

7. (a) Show that during an adiabatic expansion of an ideal monatomic gas the temperature T and volume V are given by [2]

$$TV^{\frac{2}{3}} = \text{constant}$$

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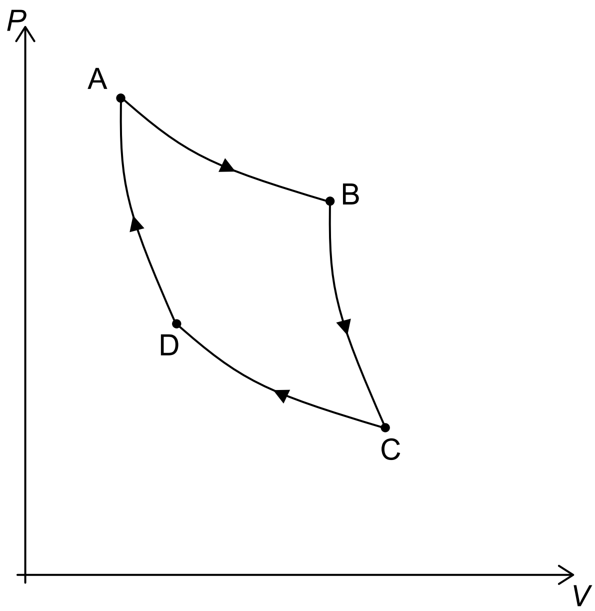
(b) The diagram shows a Carnot cycle for an ideal monatomic gas.



The highest temperature in the cycle is 620 K and the lowest is 340 K.

(i) Calculate the efficiency of the cycle. [1]

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(Option B continues on the following page)

(Option B, question 7 continued)

(ii) The work done during the isothermal expansion A → B is 540 J. Calculate the thermal energy that leaves the gas during one cycle. [2]

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(iii) Calculate the ratio $\frac{V_C}{V_B}$ where V_C is the volume of the gas at C and V_B is the volume at B. [2]

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(c) (i) Calculate the change in the entropy of the gas during the change A to B. [1]

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(ii) Explain, by reference to the second law of thermodynamics, why a real engine operating between the temperatures of 620 K and 340 K cannot have an efficiency greater than the answer to (b)(i). [2]

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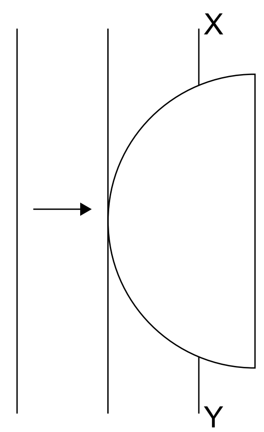
End of Option B

Option C — Imaging

8. Plane wavefronts in air are incident on the curved side of a transparent semi-circular block of refractive index 2.0.



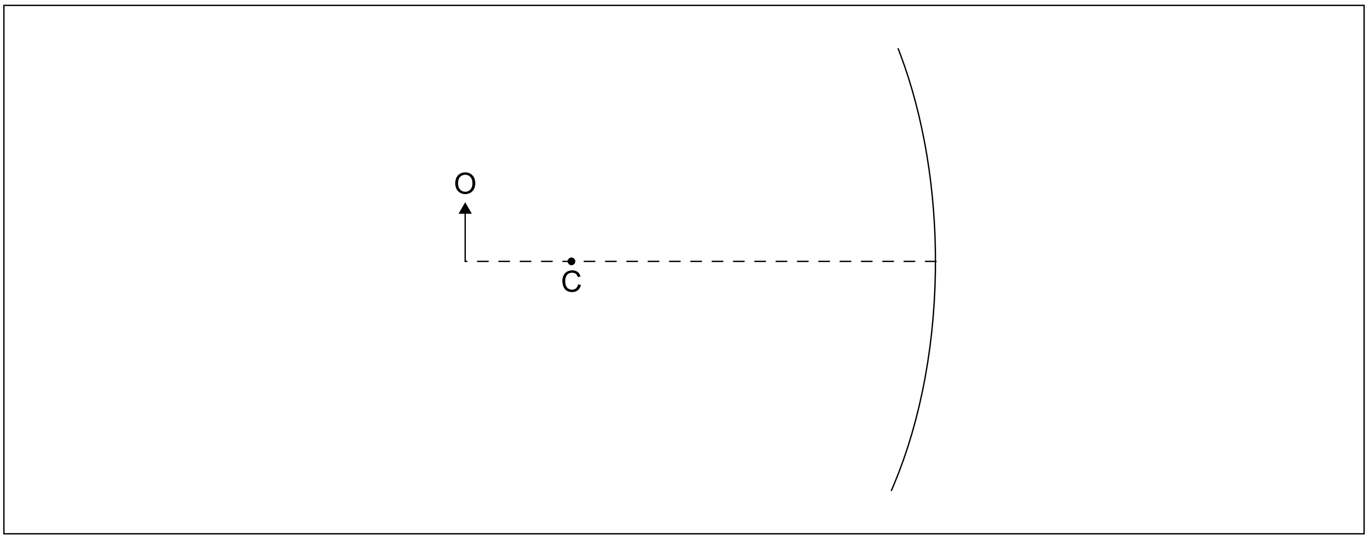
Part of wavefront XY outside the block is shown.

Draw, on the diagram, the wavefront inside the block. [2]

(Option C continues on the following page)

(Option C continued)

9. (a) An object O is placed in front of concave mirror. The centre of the mirror is labelled with the letter C.



(i) Label the focal point of the mirror with the letter F. [1]

(ii) Sketch **two** appropriate rays on the diagram to show the formation of the image. Label the image with the letter I. [3]

(iii) The upper half of the mirror is blackened so it cannot reflect any light. State the effect of this, if any, on the image. [1]

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(Option C continues on the following page)

(Option C, question 9 continued)

(b) A concave mirror of radius 3.0 m is used to form the image of the full Moon. The distance from the mirror to the Moon is 3.8×10^{8} m and the diameter of the Moon is 3.5×10^{6} m.

Determine the diameter of the image of the Moon. [3]

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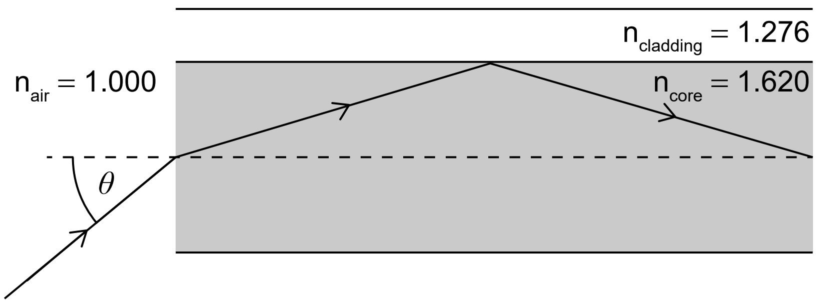
10. (a) The diagram shows a light ray incident from air into the core of an optic fibre. The angle of incidence is θ. Values of refractive indices are shown on the diagram.



(i) Calculate the critical angle at the core–cladding boundary. [2]

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(Option C continues on the following page)

(Option C, question 10 continued)

(ii) Show that the maximum value of θ for which total internal reflection will take place at the core–cladding boundary is about 90°. [3]

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(iii) Comment on your answer to part (a)(ii). [1]

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(iv) A signal consists of two rays that enter the core at angle of incidence $\theta = 0$ and $\theta = \theta_{max}$. Identify a disadvantage of this fibre for transmitting this signal [2]

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(b) Outline the significance of optic fibres in modern communications. [2]

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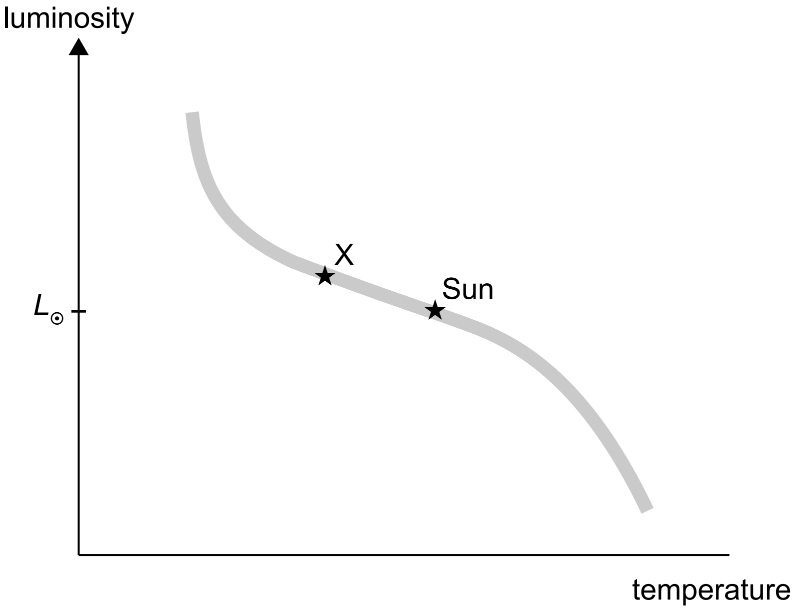
End of Option C

Option D — Astrophysics

11. The Hertzsprung–Russell (HR) diagram shows the Sun and a main sequence star X.



The following data are available for the mass and radius of star X where $M_\odot$ is the mass of the Sun and $R_\odot$ is the radius of the Sun:

$$M_X = 5.0\,M_\odot$$
$$R_X = 3.2\,R_\odot$$

(a) (i) Show that the luminosity of star X is about 280 times greater than the luminosity of the Sun $L_\odot$. [1]

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(ii) Determine the ratio $\dfrac{\text{surface temperature of star X}}{\text{surface temperature of the Sun}}$. [2]

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(Option D continues on the following page)

(Option D, question 11 continued)

(b) The parallax angle for star X is 0.125 arc-second.

(i) Outline how the parallax angle of a star can be measured. [2]

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(ii) Show that the distance to star X is 1.6×10^{6} AU. [2]

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(iii) The apparent brightness of the Sun is 1400 $W m^{-2}$. Calculate, in $W m^{-2}$, the apparent brightness of star X. [2]

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(Option D continues on the following page)

(Option D, question 11 continued)

(c) Star X will evolve to become a white dwarf star D.

(i) Label, on the HR diagram, the region of white dwarf stars. [1]

(ii) Outline the condition that prevents star D from collapsing further. [1]

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(iii) Star D emits energy into space in the form of electromagnetic radiation. State the origin of this energy. [1]

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(iv) Predict the change in luminosity of star D as time increases. [1]

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12. (a) Light from a distant galaxy observed on Earth shows a redshift of 0.15.

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

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(ii) Determine the distance to this galaxy assuming a Hubble constant of $H_0 = 72\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. [2]

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(Option D continues on the following page)

(Option D, question 12 continued)

(b) (i) The cosmic microwave background (CMB) radiation provides strong evidence for the Big Bang model. State the **two** main pieces of this evidence. [2]

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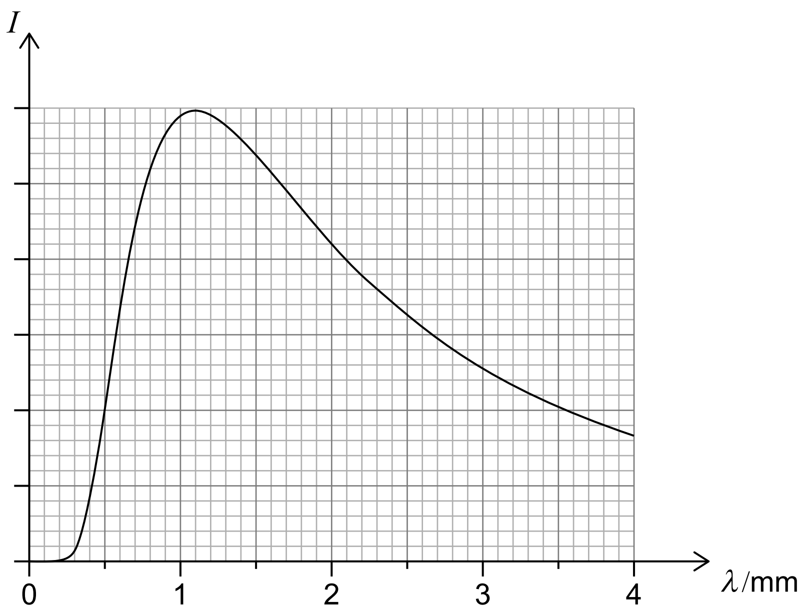
(ii) The graph shows the variation of the intensity I of the CMB with wavelength λ.



Determine, using the graph, the temperature of the CMB. [2]

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End of Option D

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