Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Standard level
Paper 3

Wednesday 9 November 2016 (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.
- Write your answers in the 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 – 3

Option	Questions
Answer all of the questions from one of the options.	
Option A — Relativity	4 – 7
Option B — Engineering physics	8 – 10
Option C — Imaging	11 – 14
Option D — Astrophysics	15 – 17

32 pages

8816 – 6506

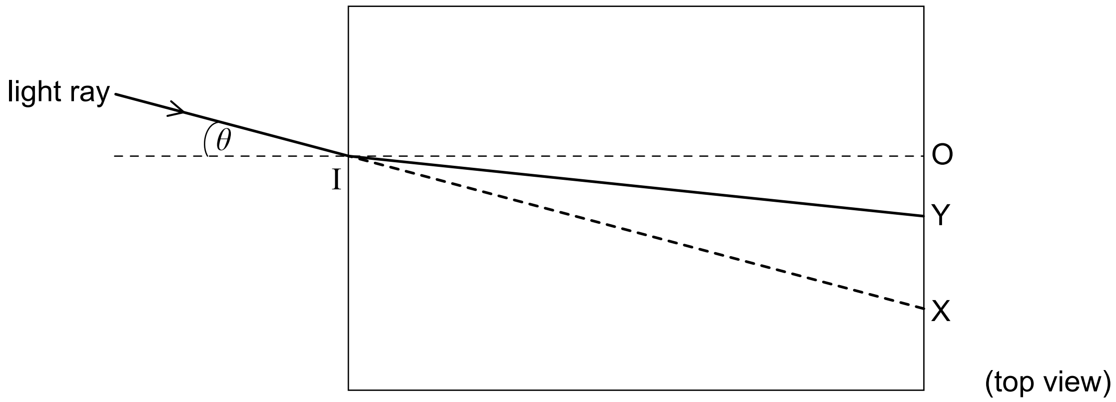
Section A

Answer **all** questions. Write your answers in the boxes provided.

1. A student measures the refractive index of water by shining a light ray into a transparent container.

IO shows the direction of the normal at the point where the light is incident on the container. IX shows the direction of the light ray when the container is empty. IY shows the direction of the deviated light ray when the container is filled with water.

The angle of incidence θ is varied and the student determines the position of O, X and Y for each angle of incidence.



(This question continues on the following page)

(Question 1 continued)

The table shows the data collected by the student. The uncertainty in each measurement of length is ±0.1 cm.

OX / cm	OY / cm
1.8	1.3
3.6	2.6
5.8	4.0
8.4	5.5
11.9	7.3
17.3	9.5
27.4	12.2

(a) (i) Outline why OY has a greater percentage uncertainty than OX for each pair of data points. [1]

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(ii) The refractive index of the water is given by $\frac{\text{OX}}{\text{OY}}$ when OX is small.

Calculate the fractional uncertainty in the value of the refractive index of water for OX = 1.8 cm. [2]

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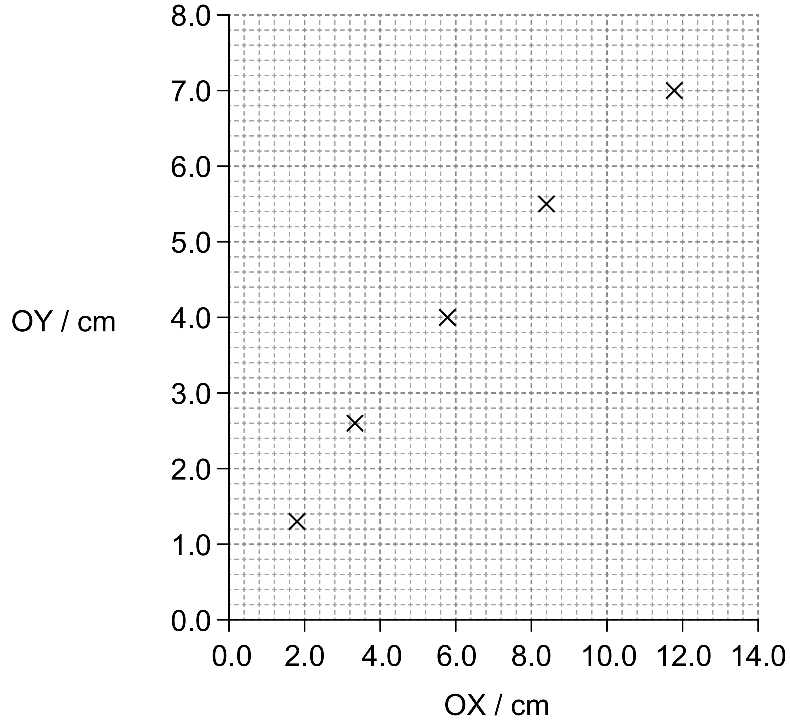
(This question continues on the following page)

(Question 1 continued)

(b) A graph of the variation of OY with OX is plotted.



(i) Draw, on the graph, the error bars for OY when OX = 1.8 cm **and** when OY = 5.8 cm. [1]

(ii) Determine, using the graph, the refractive index of the water in the container for values of OX less than 6.0 cm. [3]

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(This question continues on the following page)

(Question 1 continued)

(iii) The refractive index for a material is also given by $\frac{\sin i}{\sin r}$ where i is the angle of incidence and r is the angle of refraction.

Outline why the graph on page 4 deviates from a straight line for large values of OX. [1]

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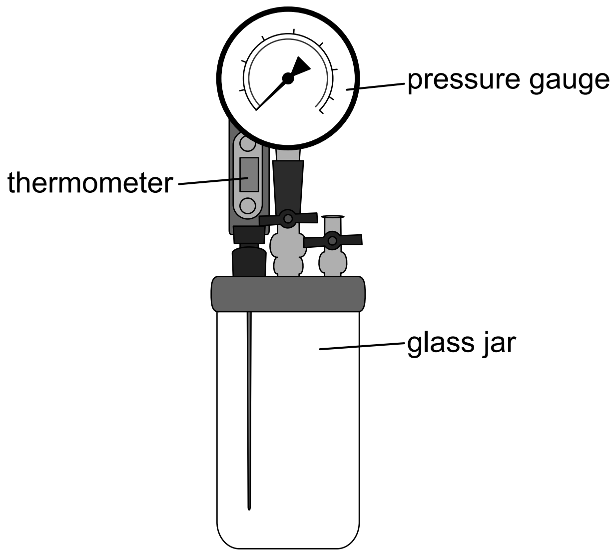
2. An apparatus is used to verify a gas law. The glass jar contains a fixed volume of air. Measurements can be taken using the thermometer and the pressure gauge.

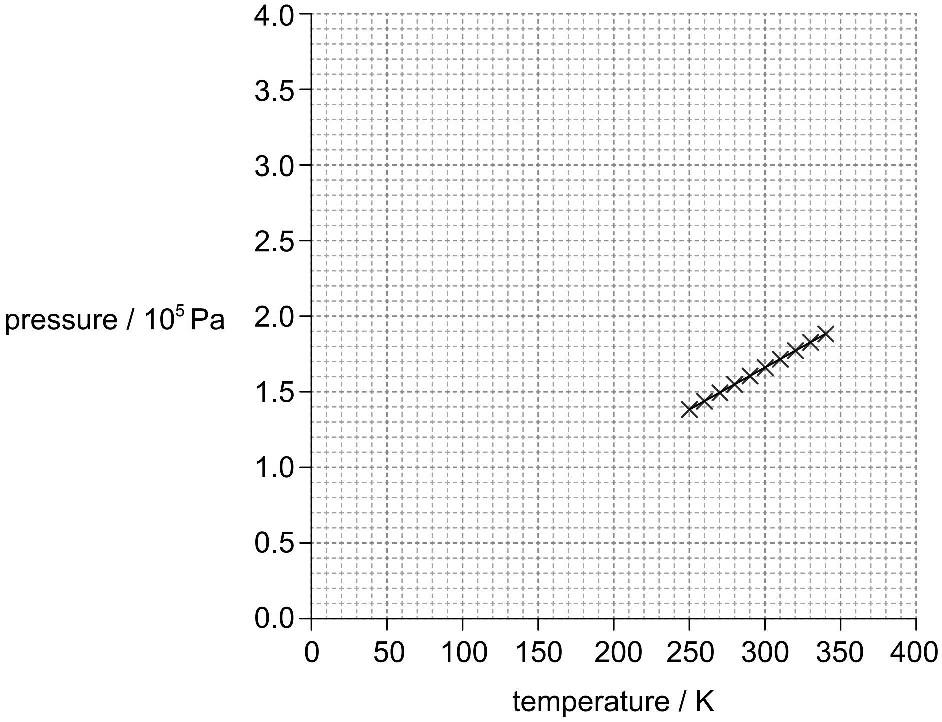


The apparatus is cooled in a freezer and then placed in a water bath so that the temperature of the gas increases slowly. The pressure and temperature of the gas are recorded.

(This question continues on the following page)

(Question 2 continued)

(a) The graph shows the data recorded.



Identify the fundamental SI unit for the gradient of the pressure–temperature graph. [1]

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(b) The experiment is repeated using a different gas in the glass jar. The pressure for both experiments is low and both gases can be considered to be ideal.

(i) Using the axes provided in (a), draw the expected graph for this second experiment. [1]

(ii) Explain the shape and intercept of the graph you drew in (b)(i). [2]

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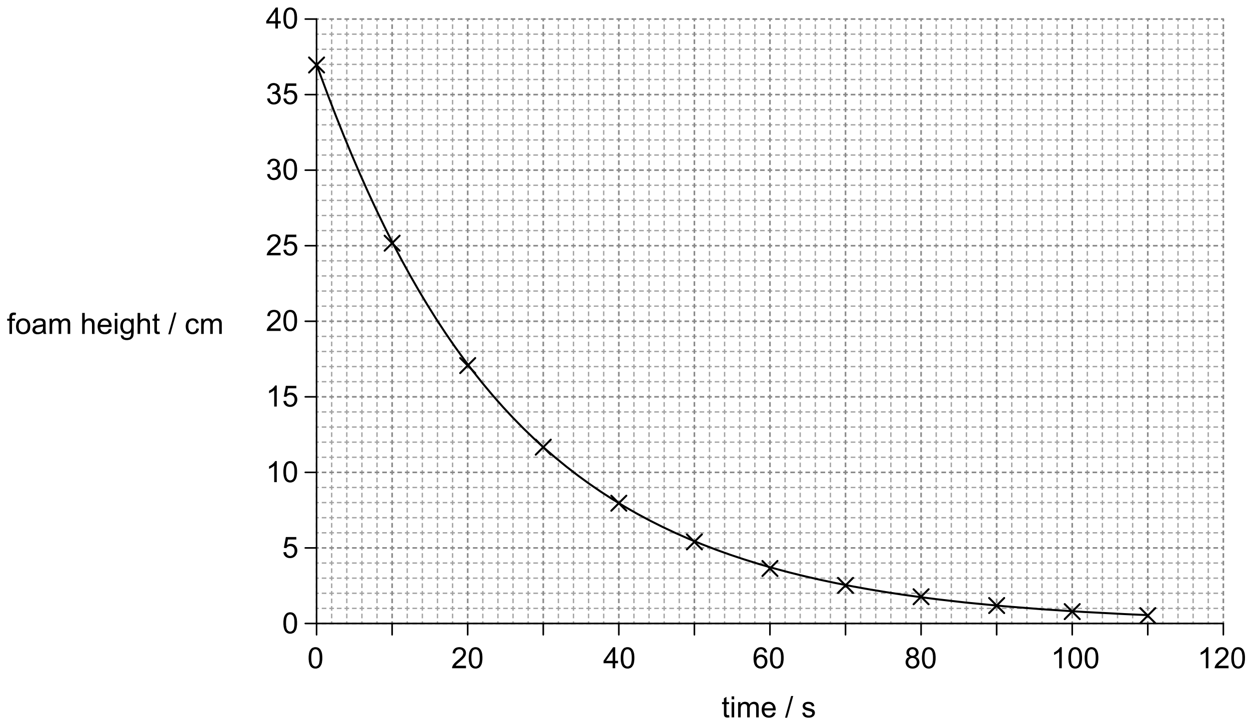
Please **do not** write on this page.

Answers written on this page
will not be marked.

3. A student pours a canned carbonated drink into a cylindrical container after shaking the can violently before opening. A large volume of foam is produced that fills the container. The graph shows the variation of foam height with time.



(a) Determine the time taken for the foam to drop to

(i) half its initial height. [1]

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(ii) a quarter of its initial height. [1]

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(b) The change in foam height can be modelled using ideas from other areas of physics. Identify **one** other situation in physics that is modelled in a similar way. [1]

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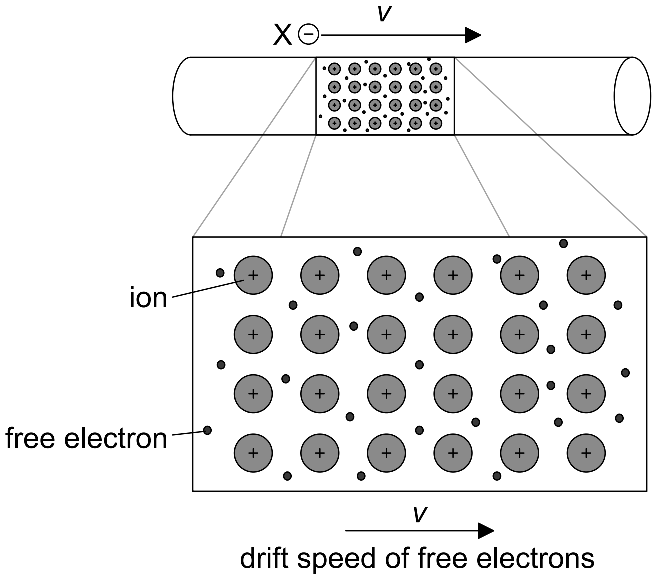
Section B

Answer **all** of the questions from **one** of the options. Write your answers in the boxes provided.

Option A — Relativity

4. An electron X is moving parallel to a current-carrying wire. The positive ions and the wire are fixed in the reference frame of the laboratory. The drift speed of the free electrons in the wire is the same as the speed of the external electron X.



(a) Define *frame of reference*. [1]

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(Option A continues on the following page)

(Option A, question 4 continued)

(b) In the reference frame of the laboratory the force on X is magnetic.

(i) State the nature of the force acting on X in this reference frame where X is at rest. [1]

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(ii) Explain how this force arises. [3]

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(Option A continues on the following page)

(Option A continued)

5. (a) Define *proper length*. [1]

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(b) A charged pion decays spontaneously in a time of 26 ns as measured in the frame of reference in which it is stationary. The pion moves with a velocity of 0.96*c* relative to the Earth. Calculate the pion's lifetime as measured by an observer on the Earth. [2]

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(c) In the pion reference frame, the Earth moves a distance X before the pion decays. In the Earth reference frame, the pion moves a distance Y before the pion decays. Demonstrate, with calculations, how length contraction applies to this situation. [3]

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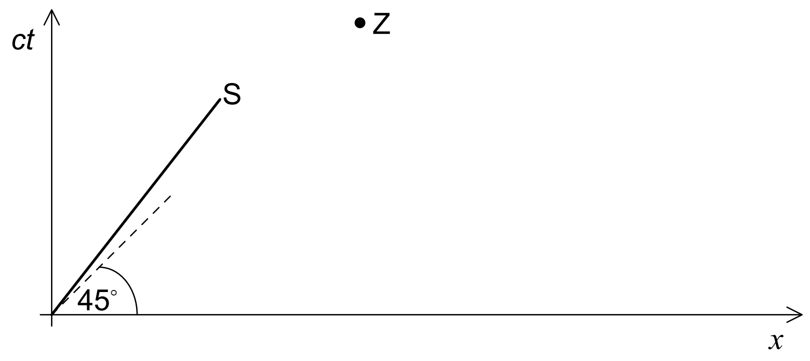
(Option A continues on the following page)

(Option A continued)

6. A spaceship S leaves the Earth with a speed $v = 0.80c$. The spacetime diagram for the Earth is shown. A clock on the Earth and a clock on the spaceship are synchronized at the origin of the spacetime diagram.



(a) Calculate the angle between the worldline of S and the worldline of the Earth. [1]

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(b) Draw, on the diagram, the x'-axis for the reference frame of S. [1]

(c) An event Z is shown on the diagram. Label the co-ordinates of this event in the reference frame of S. [1]

(Option A continues on the following page)

(Option A continued)

7. Identical twins, A and B, are initially on Earth. Twin A remains on Earth while twin B leaves the Earth at a speed of 0.6*c* for a return journey to a point three light years from Earth.

(a) Calculate the time taken for the journey in the reference frame of twin A as measured on Earth. [1]

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(b) Determine the time taken for the journey in the reference frame of twin B. [2]

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(c) Draw, for the reference frame of twin A, a spacetime diagram that represents the worldlines for both twins. [1]

(Option A continues on the following page)

(Option A, question 7 continued)

(d) Suggest how the twin paradox arises and how it is resolved. [2]

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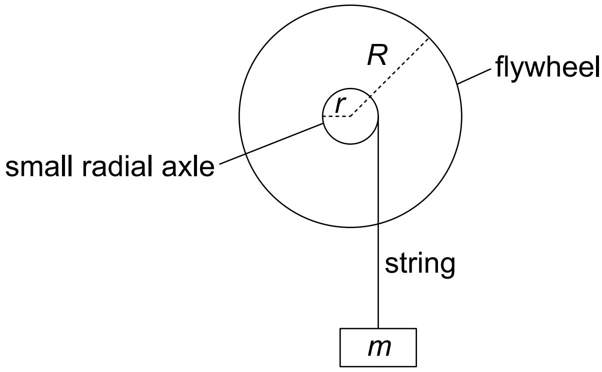
End of Option A

Option B — Engineering physics

8. A flywheel consists of a solid cylinder, with a small radial axle protruding from its centre.



The following data are available for the flywheel.

Flywheel mass $M = 1.22\,\text{kg}$
Small axle radius $r = 60.0\,\text{mm}$
Flywheel radius $R = 240\,\text{mm}$
Moment of inertia $= 0.5\,MR^2$

An object of mass m is connected to the axle by a light string and allowed to fall vertically from rest, exerting a torque on the flywheel.

(a) The velocity of the falling object is $1.89\,\text{m}\,\text{s}^{-1}$ at 3.98 s. Calculate the average angular acceleration of the flywheel. [2]

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(b) Show that the torque acting on the flywheel is about 0.3 Nm. [2]

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(Option B continues on the following page)

(Option B, question 8 continued)

(c) (i) Calculate the tension in the string. [2]

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(ii) Determine the mass m of the falling object. [2]

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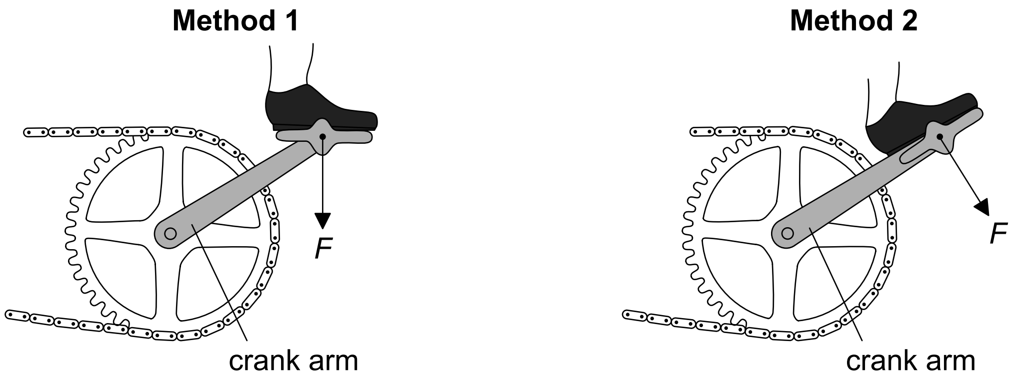
(Option B continues on the following page)

(Option B continued)

9. The diagram shows two methods of pedalling a bicycle using a force *F*.



In method 1 the pedal is always horizontal to the ground. A student claims that method 2 is better because the pedal is always parallel to the crank arm. Explain why method 2 is more effective. [2]

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10. An ideal nuclear power plant can be modelled as a heat engine that operates between a hot temperature of 612 °C and a cold temperature of 349 °C.

(a) Calculate the Carnot efficiency of the nuclear power plant. [2]

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(Option B continues on the following page)

(Option B, question 10 continued)

(b) Explain, with a reason, why a real nuclear power plant operating between the stated temperatures cannot reach the efficiency calculated in (a). [2]

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(c) The nuclear power plant works at 71.0 % of the Carnot efficiency. The power produced is 1.33 GW. Calculate how much waste thermal energy is released per hour. [3]

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(d) Discuss the production of waste heat by the power plant with reference to the first law and the second law of thermodynamics. [3]

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End of Option B

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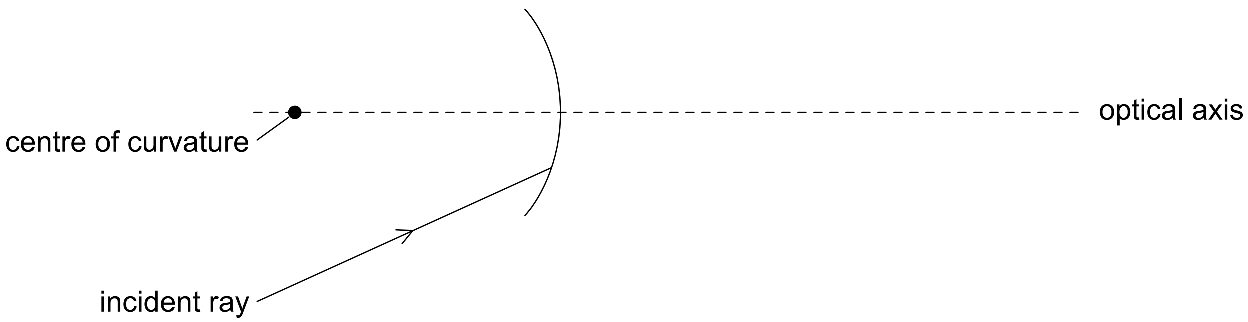
will not be marked.

Option C — Imaging

11. Spherical converging mirrors are reflecting surfaces which are cut out of a sphere. The diagram shows a mirror, where the dot represents the centre of curvature of the mirror.

(a) A ray of light is incident on a converging mirror. On the diagram, draw the reflection of the incident ray shown. [2]



(b) The incident ray shown in the diagram makes a significant angle with the optical axis.

(i) State the aberration produced by these kind of rays. [1]

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(ii) Outline how this aberration is overcome. [1]

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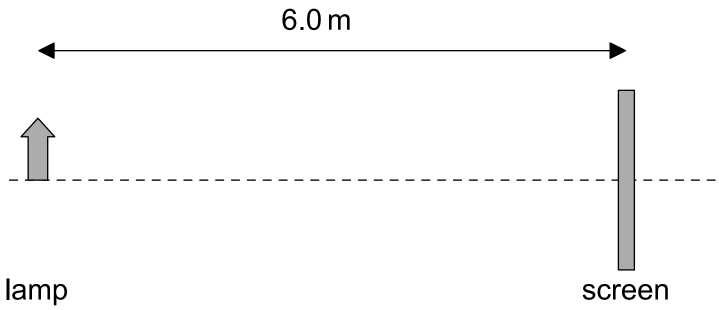
(Option C continues on the following page)

(Option C continued)

12. A lamp is located 6.0 m from a screen.



Somewhere between the lamp and the screen, a lens is placed so that it produces a real inverted image on the screen. The image produced is 4.0 times larger than the lamp.

(a) Identify the nature of the lens. [1]

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(b) Determine the distance between the lamp and the lens. [3]

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(c) Calculate the focal length of the lens. [1]

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(Option C continues on the following page)

(Option C, question 12 continued)

(d) The lens is moved to a second position where the image on the screen is again focused. The lamp–screen distance does not change. Compare the characteristics of this new image with the original image. [2]

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(Option C continues on the following page)

(Option C continued)

13. Both optical refracting telescopes and compound microscopes consist of two converging lenses.

(a) Compare the focal lengths needed for the objective lens in an refracting telescope and in a compound microscope. [1]

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(b) A student has four converging lenses of focal length 5, 20, 150 and 500 mm. Determine the maximum magnification that can be obtained with a refracting telescope using **two** of the lenses. [1]

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(c) There are optical telescopes which have diameters about 10 m. There are radio telescopes with single dishes of diameters at least 10 times greater.

(i) Discuss why, for the same number of incident photons per unit area, radio telescopes need to be much larger than optical telescopes. [1]

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(ii) Outline how is it possible for radio telescopes to achieve diameters of the order of a thousand kilometres. [1]

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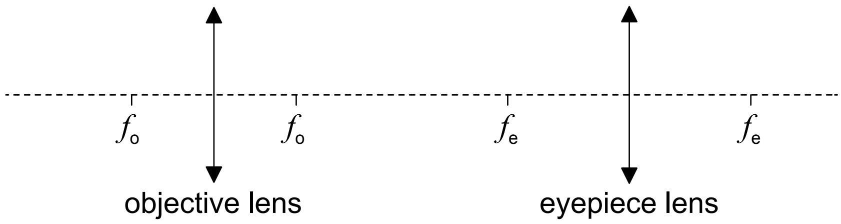
(Option C continues on the following page)

(Option C, question 13 continued)

(d) The diagram shows a schematic view of a compound microscope with the focal points f_o of the objective lens and the focal points f_e of the eyepiece lens marked on the axis.



On the diagram, identify with an X, a suitable position for the image formed by the objective of the compound microscope. [1]

(e) Image 1 shows details on the petals of a flower under visible light. Image 2 shows the same flower under ultraviolet light. The magnification is the same, but the resolution is higher in Image 2.

Image 1 Image 2

Explain why an ultraviolet microscope can increase the resolution of a compound microscope. [1]

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(Option C continues on page 27)

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will not be marked.

(Option C continued from page 25)

14. Optical fibres can be classified, based on the way the light travels through them, as single-mode or multimode fibres. Multimode fibres can be classified as step-index or graded-index fibres.

(a) State the main physical difference between step-index and graded-index fibres. [1]

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(b) Explain why graded-index fibres help reduce waveguide dispersion. [2]

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End of Option C

Option D — Astrophysics

15. Alpha Centauri A and B is a binary star system in the main sequence.

	Alpha Centauri A	**Alpha Centauri B**
Luminosity	$1.5L_{\odot}$	$0.5L_{\odot}$
Surface temperature / K	5800	5300

(a) State what is meant by a binary star system. [1]

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(b) (i) Calculate $\frac{b_A}{b_B} = \frac{\text{apparent brightness of Alpha Centauri A}}{\text{apparent brightness of Alpha Centauri B}}$. [2]

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(ii) The luminosity of the Sun is 3.8×10^{26} W. Calculate the radius of Alpha Centauri A. [2]

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(Option D continues on the following page)

(Option D, question 15 continued)

(c) Show, without calculation, that the radius of Alpha Centauri B is smaller than the radius of Alpha Centauri A. [2]

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(d) Alpha Centauri A is in equilibrium at constant radius. Explain how this equilibrium is maintained. [3]

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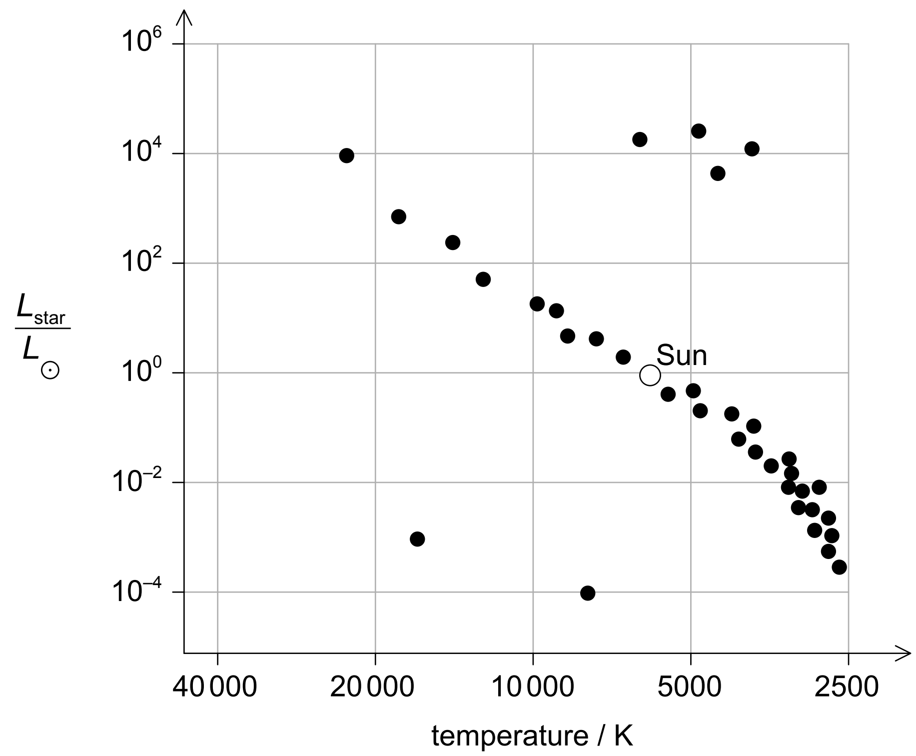
(Option D continues on the following page)

(Option D, question 15 continued)

(e) A standard Hertzsprung–Russell (HR) diagram is shown.

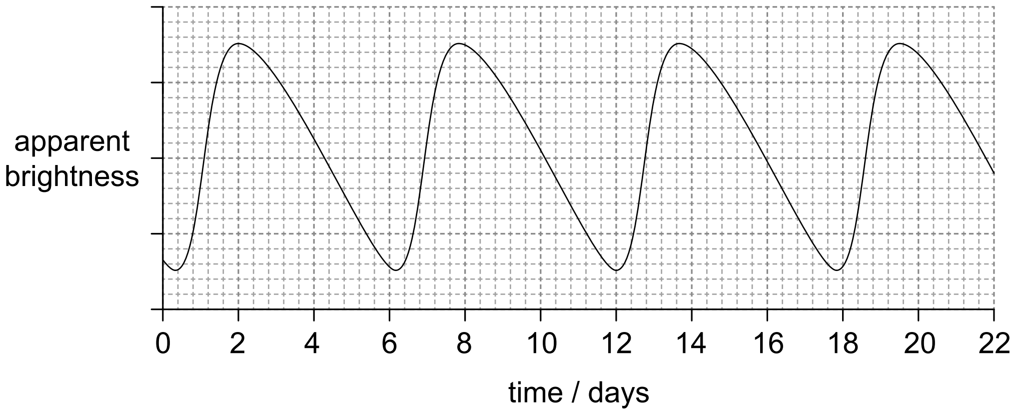


Using the HR diagram, draw the present position of Alpha Centauri A and its expected evolutionary path. [2]

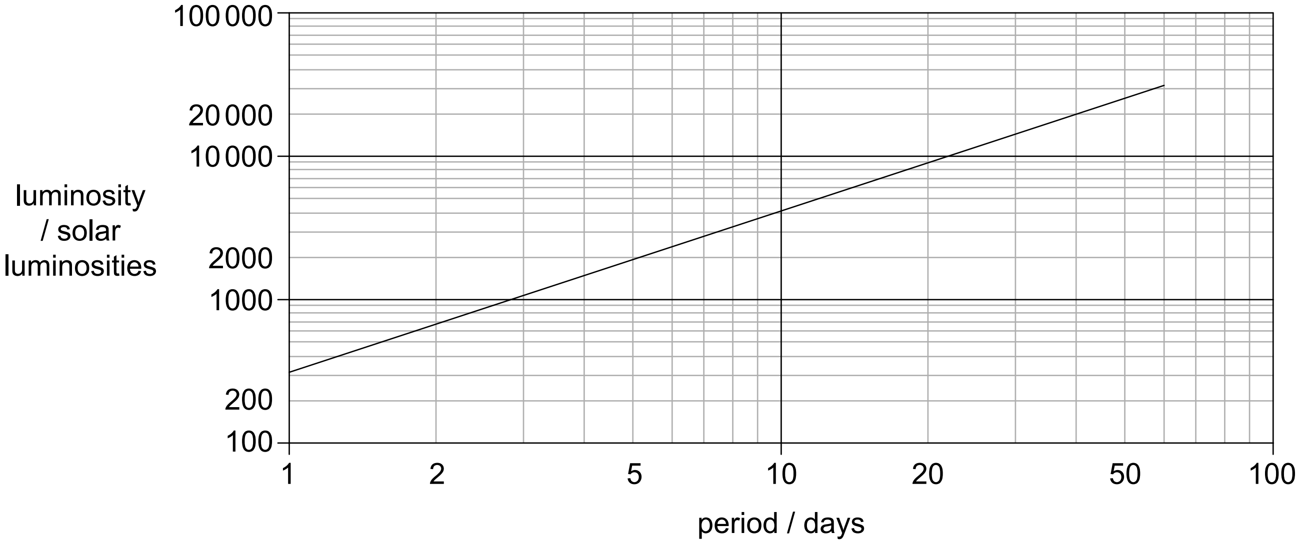
(Option D continues on the following page)

(Option D continued)

16. The first graph shows the variation of apparent brightness of a Cepheid star with time.



The second graph shows the average luminosity with period for Cepheid stars.



(a) Determine the distance from Earth to the Cepheid star in parsecs. The luminosity of the Sun is 3.8×10^{26} W. The average apparent brightness of the Cepheid star is 1.1×10^{-9} W m^{-2}. [3]

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(Option D continues on the following page)

(Option D, question 16 continued)

(b) Explain why Cephids are used as standard candles. [2]

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17. The peak wavelength of the cosmic microwave background (CMB) radiation spectrum corresponds to a temperature of 2.76 K.

(a) Identify **two** other characteristics of the CMB radiation that are predicted from the Hot Big Bang theory. [2]

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(b) A spectral line in the hydrogen spectrum measured in the laboratory today has a wavelength of 21 cm. Since the emission of the CMB radiation, the cosmic scale factor has changed by a factor of 1100. Determine the wavelength of the 21 cm spectral line in the CMB radiation when it is observed today. [1]

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End of Option D