Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 3

Wednesday 1 November 2017 (morning)

Candidate session number

1 hour 15 minutes

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 **[45 marks]**.

Section A	Questions
Answer all questions.	1 – 3

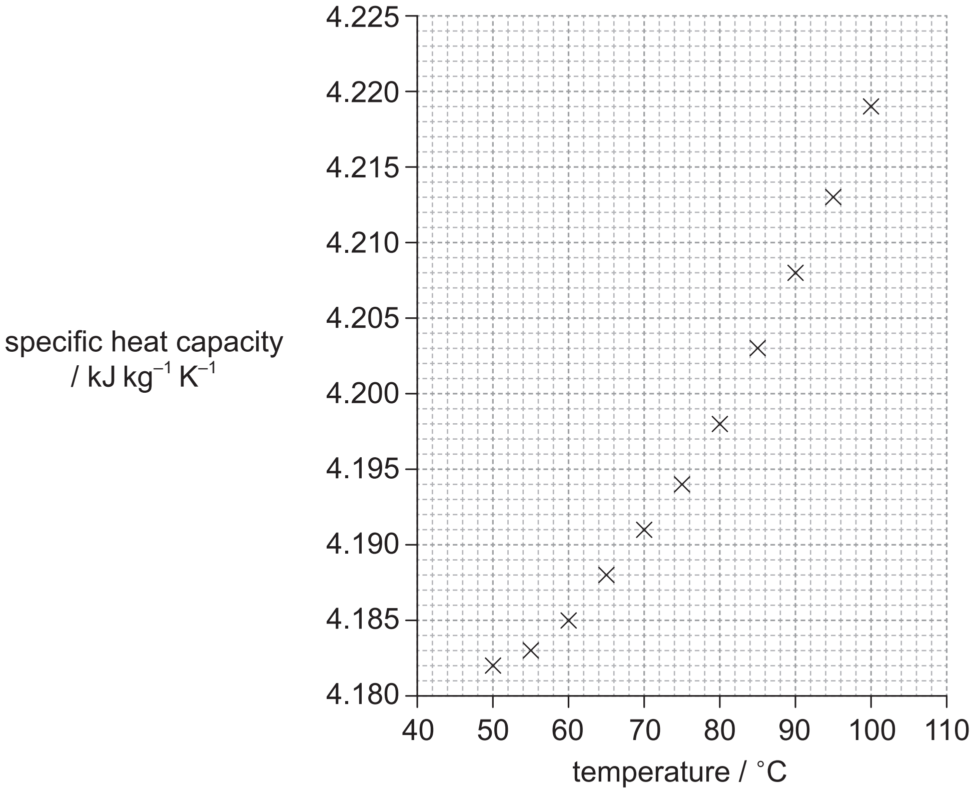
Section B	Questions
Answer all of the questions from one of the options.	
Option A — Relativity	4 – 8
Option B — Engineering physics	9 – 12
Option C — Imaging	13 – 16
Option D — Astrophysics	17 – 20

8817 – 6503
36 pages

Section A

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

1. In an experiment, data were collected on the variation of specific heat capacity of water with temperature. The graph of the plotted data is shown.



(a) Draw the line of best-fit for the data. [1]

(This question continues on the following page)

(Question 1 continued)

(b) (i) Determine the gradient of the line at a temperature of 80 °C. [3]

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(ii) State the unit for the quantity represented by the gradient in your answer to (b)(i). [1]

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(c) The uncertainty in the values for specific heat capacity is 5 %.
Water of mass (100 ± 2) g is heated from (75.0 ± 0.5) °C to (85.0 ± 0.5) °C.

(i) Calculate the energy required to raise the temperature of the water from 75 °C to 85 °C. [1]

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(ii) Using an appropriate error calculation, justify the number of significant figures that should be used for your answer to (c)(i). [3]

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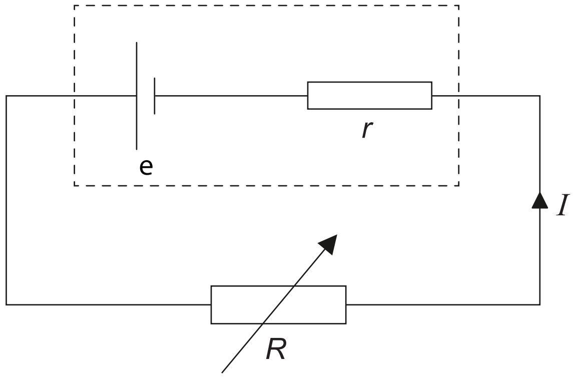
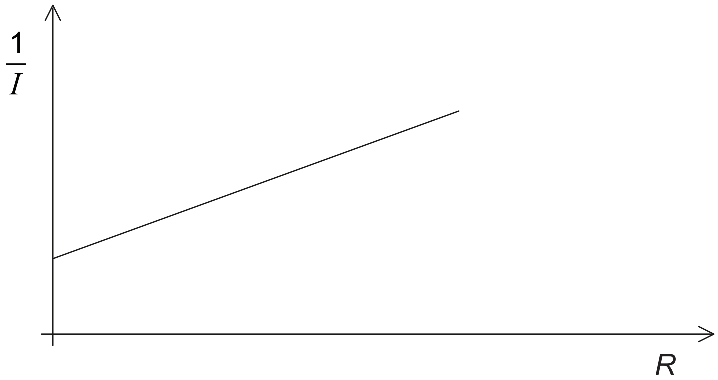
2. An electrical circuit is used during an experiment to measure the current I in a variable resistor of resistance *R*. The emf of the cell is e and the cell has an internal resistance *r*.



A graph shows the variation of $\frac{1}{I}$ with *R*.



(a) Show that the gradient of the graph is equal to $\frac{1}{e}$. [2]

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(b) State the value of the intercept on the *R* axis. [1]

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3. A student is running an experiment to determine the acceleration of free-fall g. She drops a small metal ball from a given height and measures the time t taken for it to fall using an electronic timer. She repeats the same experiment several times.

(a) Suggest a reason for repeating the experiment in the same conditions. [1]

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(b) With the collected data she determines the value of g to be $(10.4 \pm 0.7)\,\text{m s}^{-2}$. Researching scientific literature about the location of her experiment she finds the value of g to be $(9.807 \pm 0.006)\,\text{m s}^{-2}$. State, with a reason, whether her experiment is accurate. [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

4. Outline the conclusion from Maxwell's work on electromagnetism that led to one of the postulates of special relativity. [2]

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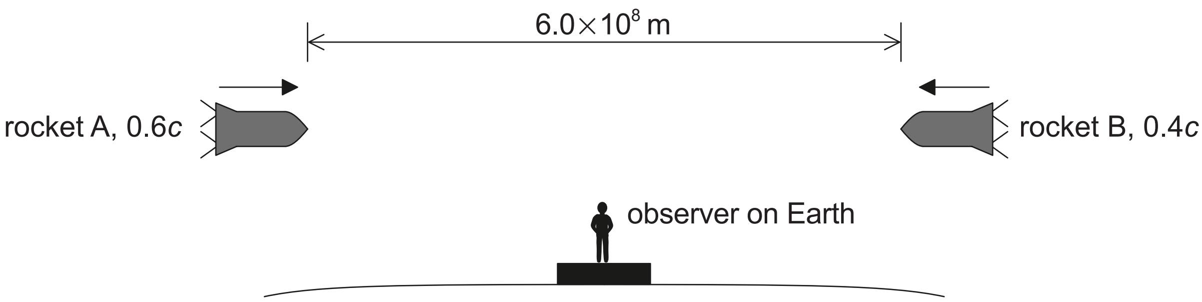
5. Two rockets, A and B, are moving towards each other on the same path. From the frame of reference of the Earth, an observer measures the speed of A to be 0.6c and the speed of B to be 0.4c. According to the observer on Earth, the distance between A and B is 6.0×10^{8} m.



(a) Define frame of reference. [1]

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(Option A continues on the following page)

(Option A, question 5 continued)

(b) Calculate, according to the observer on Earth, the time taken for A and B to meet. [2]

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(c) Identify the terms in the formula. [1]

$$u' = \frac{u - v}{1 - \frac{uv}{c^2}}$$

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(d) Determine, according to an observer in A, the velocity of B. [2]

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(Option A continues on page 9)

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will not be marked.

(Option A, question 5 continued from page 7)

(e) (i) Determine, according to an observer in A, the time taken for B to meet A. [2]

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(ii) Deduce, without further calculation, how the time taken for A to meet B, according to an observer in B, compares with the time taken for the same event according to an observer in A. [2]

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(Option A continues on the following page)

(Option A continued)

6. A train is passing through a tunnel of proper length 80 m. The proper length of the train is 100 m. According to an observer at rest relative to the tunnel, when the front of the train coincides with one end of the tunnel, the rear of the train coincides with the other end of the tunnel.

(a) Explain what is meant by proper length. [1]

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(b) Draw a spacetime diagram for this situation according to an observer at rest relative to the tunnel. [3]

(c) Calculate the velocity of the train, according to an observer at rest relative to the tunnel, at which the train fits the tunnel. [2]

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(Option A continues on the following page)

(Option A, question 6 continued)

(d) For an observer on the train, it is the tunnel that is moving and therefore will appear length contracted. This seems to contradict the observation made by the observer at rest to the tunnel, creating a paradox. Explain how this paradox is resolved. You may refer to your spacetime diagram in (b). [2]

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(Option A continues on the following page)

(Option A continued)

7. The Λ^0 (Lambda) particle decays spontaneously into a proton and a negatively charged pion of rest mass 140 MeV c^{-2}. After the decay, the particles are moving in the same direction with a proton momentum of 630 MeV c^{-1} and a pion momentum of 270 MeV c^{-1}.

(a) Determine the rest mass of the Λ^0 particle. [4]

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(b) Determine, using your answer to (a), the initial speed of the Λ^0 particle. [2]

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(Option A continues on the following page)

(Option A continued)

8. The Schwarzschild radius of a black hole is 6.0×10^{5} m. A rocket is 7.0×10^{8} m from the black hole and has a clock. The proper time interval between the ticks of the clock on the rocket is 1.0 s. These ticks are transmitted to a distant observer in a region free of gravitational fields.

(a) Outline why the clock near the black hole runs slowly compared to a clock close to the distant observer. [2]

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(b) Calculate the number of ticks detected in 10 ks by the distant observer. [2]

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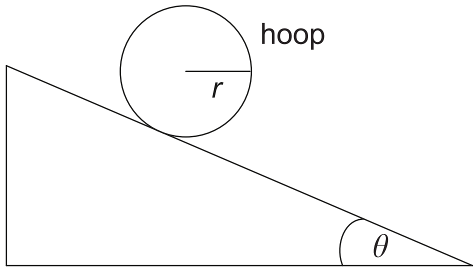
End of Option A

Option B — Engineering physics

9. A hoop of mass *m*, radius *r* and moment of inertia mr^2 rests on a rough plane inclined at an angle θ to the horizontal. It is released so that the hoop gains linear and angular acceleration by rolling, without slipping, down the plane.



(a) On the diagram, draw and label the forces acting on the hoop. [2]

(b) Show that the linear acceleration *a* of the hoop is given by the equation shown. [4]

$$a = \frac{g \times \text{sinq}}{2}$$

(Option B continues on the following page)

(Option B, question 9 continued)

(c) Calculate the linear acceleration of the hoop when $\theta = 20^{\circ}$. Assume that the hoop continues to roll without slipping. [1]

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(d) State the relationship between the force of friction and the angle of the incline. [2]

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(e) The angle of the incline is slowly increased from zero. Determine the angle, in terms of the coefficient of friction, at which the hoop will begin to slip. [3]

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(Option B continues on the following page)

(Option B continued)

10. A monatomic ideal gas is confined to a cylinder with volume $2.0\times10^{-3}\,m^3$. The initial pressure of the gas is 100 kPa. The gas undergoes a three-step cycle. First, the gas pressure increases by a factor of five under constant volume. Then, the gas expands adiabatically to its initial pressure. Finally it is compressed at constant pressure to its initial volume.

(a) Show that the volume of the gas at the end of the adiabatic expansion is approximately $5.3\times10^{-3}\,m^3$. [2]

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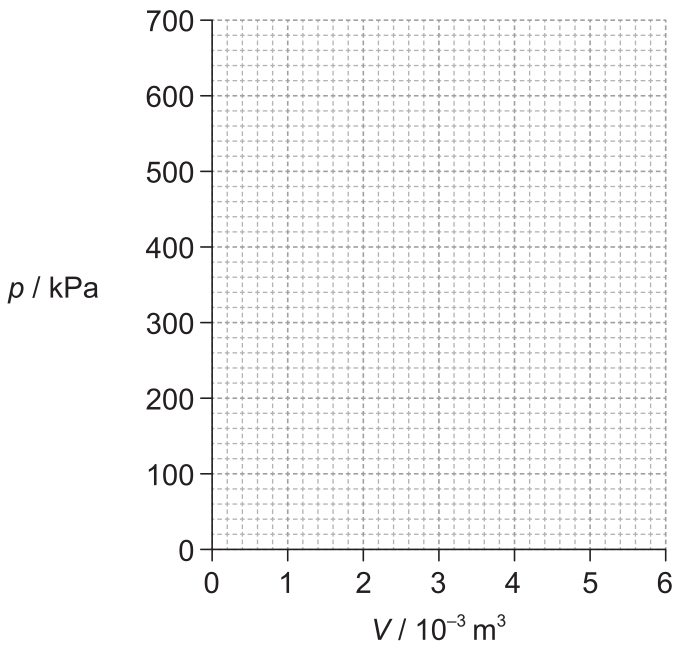
(b) Using the axes, sketch the three-step cycle. [2]



(Option B continues on the following page)

(Option B, question 10 continued)

(c) The initial temperature of the gas is 290 K. Calculate the temperature of the gas at the start of the adiabatic expansion. [2]

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(d) Using your sketched graph in (b), identify the feature that shows that net work is done by the gas in this three-step cycle. [2]

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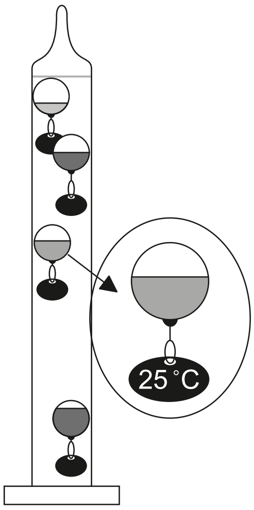
(Option B continues on the following page)

(Option B continued)

11. The diagram shows a simplified model of a Galilean thermometer. The thermometer consists of a sealed glass cylinder that contains ethanol, together with glass spheres. The spheres are filled with different volumes of coloured water. The mass of the glass can be neglected as well as any expansion of the glass through the temperature range experienced.

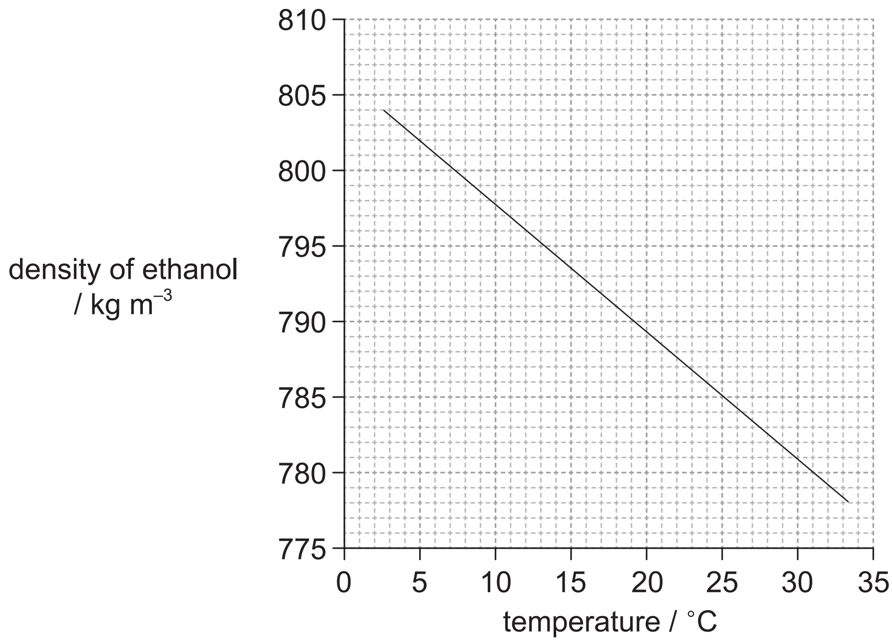
Spheres have tags to identify the temperature. The mass of the tags can be neglected in all calculations.



not to scale

Each sphere has a radius of 3.0 cm and the spheres, due to the different volumes of water in them, are of varying densities. As the temperature of the ethanol changes the individual spheres rise or fall, depending on their densities, compared with that of the ethanol.

(a) The graph shows the variation with temperature of the density of ethanol.



(Option B continues on the following page)

(Option B, question 11 continued)

(i) Using the graph, determine the buoyancy force acting on a sphere when the ethanol is at a temperature of 25 °C. [2]

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(ii) When the ethanol is at a temperature of 25 °C, the 25 °C sphere is just at equilibrium. This sphere contains water of density 1080 kg m^{-3}. Calculate the percentage of the sphere volume filled by water. [2]

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(b) The room temperature slightly increases from 25 °C, causing the buoyancy force to decrease. For this change in temperature, the ethanol density decreases from 785.20 kg m^{-3} to 785.16 kg m^{-3}. The average viscosity of ethanol over the temperature range covered by the thermometer is 0.0011 Pa s. Estimate the steady velocity at which the 25 °C sphere falls. [2]

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(Option B continues on page 21)

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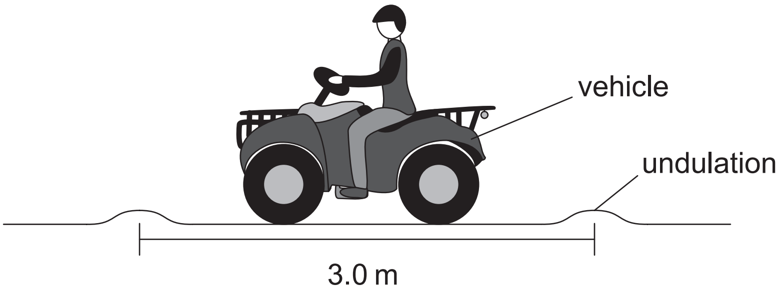
(Option B continued from page 19)

12. A farmer is driving a vehicle across an uneven field in which there are undulations every 3.0 m.



The farmer's seat is mounted on a spring. The system, consisting of the mass of the farmer and the spring, has a natural frequency of vibration of 1.9 Hz.

(a) Explain why it would be uncomfortable for the farmer to drive the vehicle at a speed of 5.6 m s^{-1}. [3]

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(b) Outline what change would be required to the value of *Q* for the mass–spring system in order for the drive to be more comfortable. [1]

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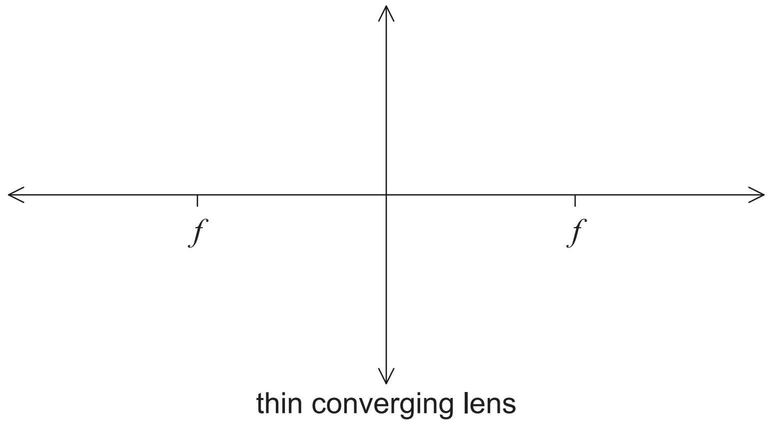
End of Option B

Option C — Imaging

13. A magnifying glass is constructed from a thin converging lens.

(a) (i) Sketch a ray diagram to show how the magnifying glass produces an upright image. [2]



(ii) State the maximum possible distance from an object to the lens in order for the lens to produce an upright image. [1]

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(Option C continues on the following page)

(Option C, question 13 continued)

(b) A converging lens can also be used to produce an image of a distant object. The base of the object is positioned on the principal axis of the lens at a distance of 10.0 m from the centre of the lens. The lens has a focal length of 2.0 m.

(i) Determine the position of the image. [2]

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(ii) State **three** characteristics of the image. [1]

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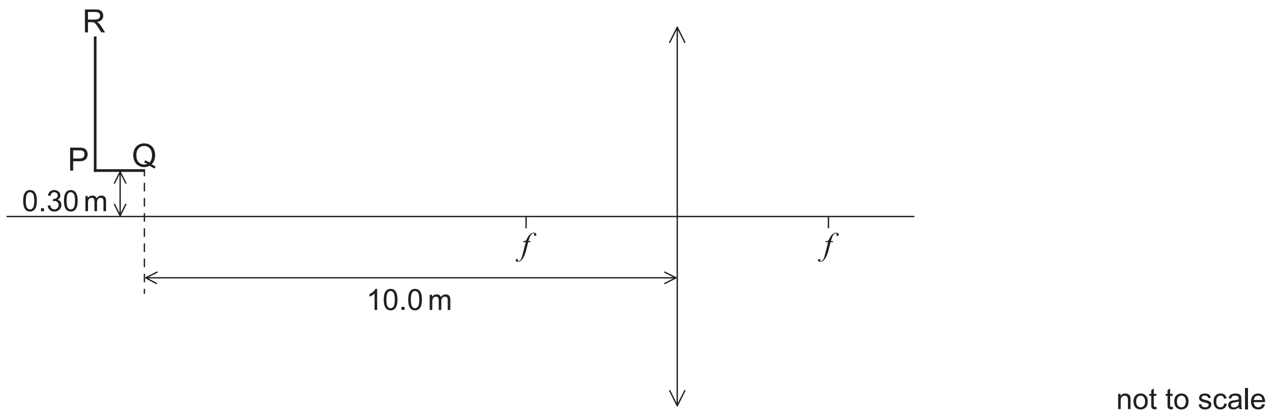
(Option C continues on the following page)

(Option C, question 13 continued)

(c) The object is replaced with an L shape that is positioned 0.30 m vertically above the principal axis as shown. A screen is used to form a focused image of part of the L shape. Two points P and Q on the base of the L shape and R on its top, are indicated on the diagram. Point Q is 10.0 m away from the same lens as used in part (b).



(i) On the diagram, draw **two** rays to locate the point Q′ on the image that corresponds to point Q on the L shape. [2]

(ii) Calculate the vertical distance of point Q′ from the principal axis. [2]

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(iii) A screen is positioned to form a focused image of point Q. State the direction, relative to Q, in which the screen needs to be moved to form a focused imaged of point R. [1]

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(Option C continues on the following page)

(Option C, question 13 continued)

(iv) The screen is now correctly positioned to form a focused image of point R. However, the top of the L shape looks distorted. Identify and explain the reason for this distortion. [2]

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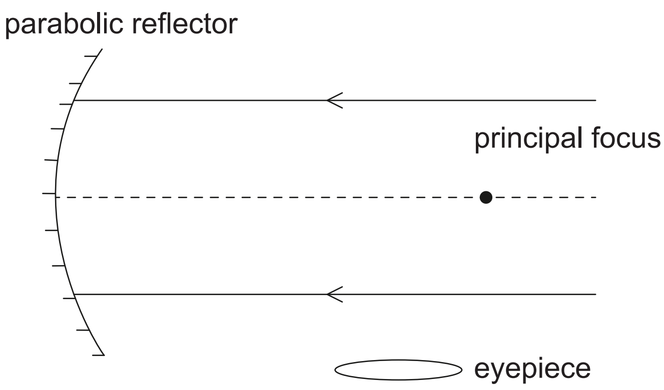
(Option C continues on the following page)

(Option C continued)

14. An astronomical reflecting telescope is being used to observe the night sky.

The diagram shows an incomplete reflecting telescope.



(a) Complete the diagram, with a Newtonian mounting, continuing the **two** rays to show how they pass through the eyepiece. [3]

(b) When the Earth-Moon distance is 363 300 km, the Moon is observed using the telescope. The mean radius of the Moon is 1737 km. Determine the focal length of the mirror used in this telescope when the diameter of the Moon's image formed by the main mirror is 1.20 cm. [2]

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(c) The final image of the Moon is observed through the eyepiece. The focal length of the eyepiece is 5.0 cm. Calculate the magnification of the telescope. [1]

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(Option C continues on the following page)

(Option C, question 14 continued)

(d) The Hubble Space reflecting telescope has a Cassegrain mounting. Identify the main optical difference between a Cassegrain mounting and a Newtonian mounting. [1]

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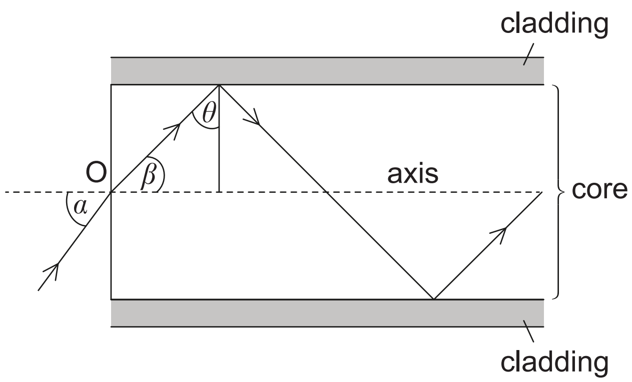
(Option C continues on the following page)

(Option C continued)

15. Some optic fibres consist of a core surrounded by cladding as shown in the diagram.



(a) Calculate the maximum angle β for light to travel through the fibre. [3]

Refractive index of core $= 1.50$
Refractive index of cladding $= 1.48$

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(b) Outline how the combination of core and cladding reduces the overall dispersion in the optic fibres. [3]

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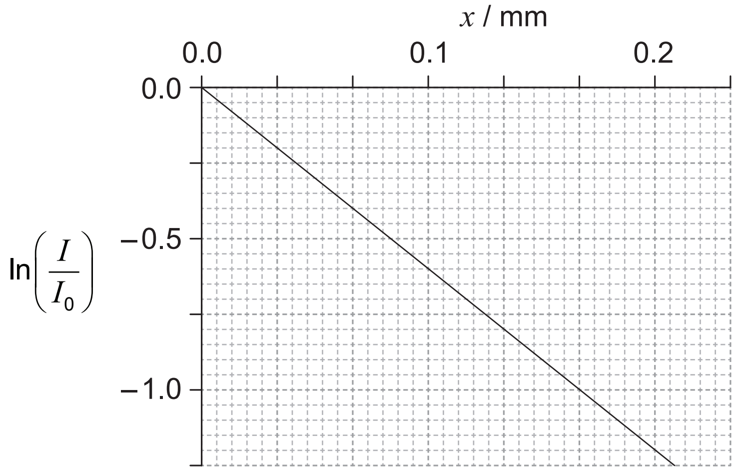
(Option C continues on the following page)

(Option C continued)

16. An X-ray beam of intensity I_0 is incident on lead. After travelling a distance x through the lead the intensity of the beam is reduced to I.

The graph shows the variation of $\ln\left(\frac{I}{I_0}\right)$ with x.



(a) Show that the attenuation coefficient of lead is 60 cm^{-1}. [2]

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(b) A technician operates an X-ray machine that takes 100 images each day. Estimate the width of the lead screen that is required so that the total exposure of the technician in 250 working days is equal to the exposure that the technician would receive from one X-ray exposure without the lead screen. [2]

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End of Option C

Option D — Astrophysics

17. Two of the brightest objects in the night sky are the planet Jupiter and the star Vega. The light observed from Jupiter has a similar brightness to that received from Vega.

(a) (i) Identify the mechanism leading stars to produce the light they emit. [1]

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(ii) Outline why the light detected from Jupiter and Vega have a similar brightness, according to an observer on Earth. [2]

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(Option D continues on the following page)

(Option D, question 17 continued)

(b) Vega is found in the constellation Lyra. The stellar parallax angle of Vega is about 0.13 arc sec.

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

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(ii) Outline how the stellar parallax angle is measured. [2]

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(iii) Show that the distance to Vega from Earth is about 25 ly. [2]

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(Option D continues on the following page)

(Option D continued)

18. Sirius is a binary star. It is composed of two stars, Sirius A and Sirius B. Sirius A is a main sequence star.

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

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(b) The peak spectral line of Sirius B has a measured wavelength of 115 nm. Show that the surface temperature of Sirius B is about 25 000 K. [1]

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(c) The mass of Sirius B is about the same mass as the Sun. The luminosity of Sirius B is 2.5 % of the luminosity of the Sun. Show, with a calculation, that Sirius B is **not** a main sequence star. [2]

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(Option D continues on the following page)

(Option D, question 18 continued)

(d) The Sun's surface temperature is about 5800 K.

(i) Determine the radius of Sirius B in terms of the radius of the Sun. [2]

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(ii) Identify the star type of Sirius B. [1]

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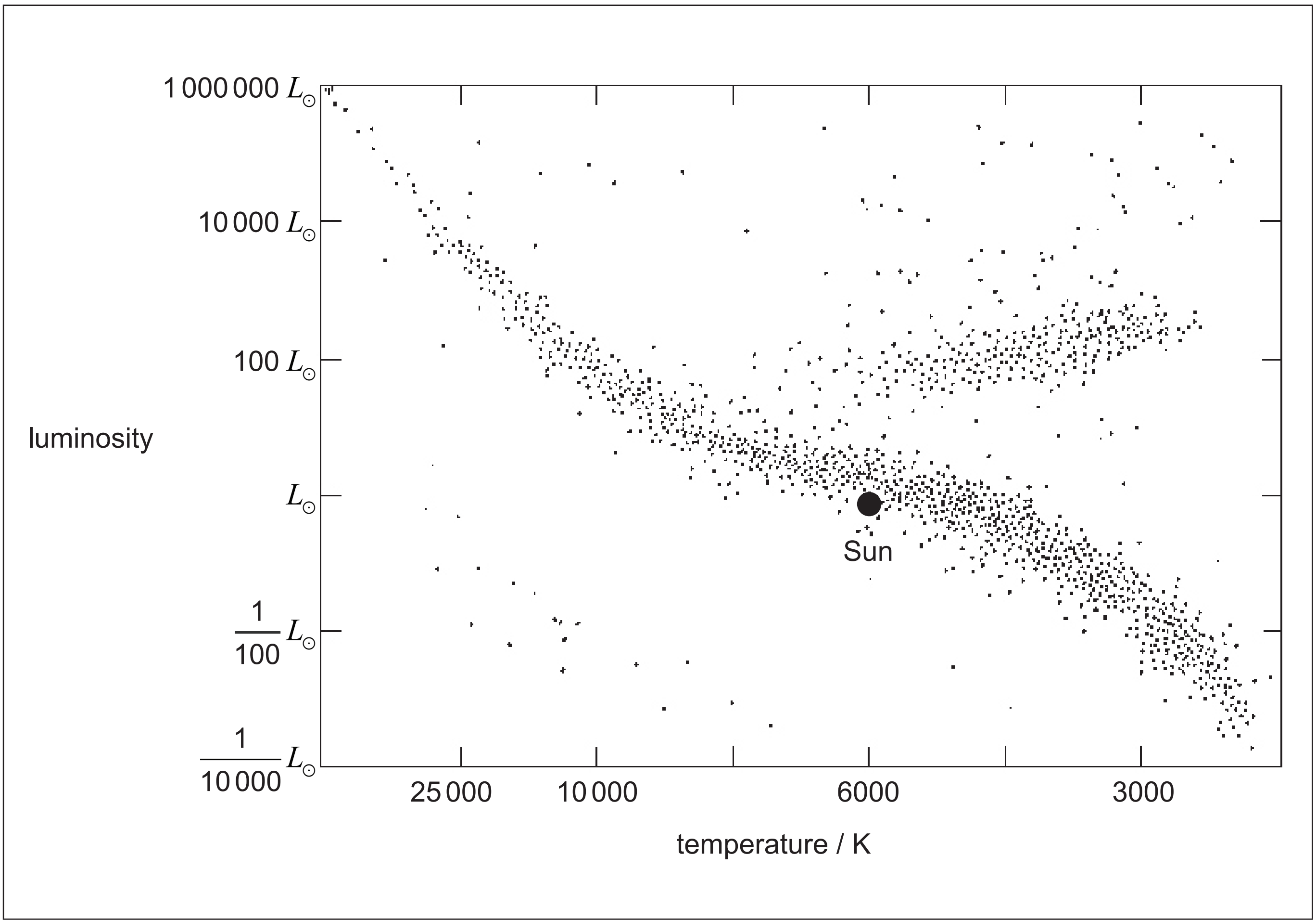
(Option D continues on the following page)

(Option D, question 18 continued)

(e) The image shows a Hertzsprung–Russell (HR) diagram.



The mass of Sirius A is twice the mass of the Sun. Using the Hertzsprung–Russell (HR) diagram,

(i) draw the approximate positions of Sirius A, labelled A and Sirius B, labelled B. [1]

(ii) sketch the expected evolutionary path for Sirius A. [1]

(Option D continues on the following page)

(Option D continued)

19. The collision of two galaxies is being studied. The wavelength of a particular spectral line from the galaxy measured from Earth is 116.04 nm. The spectral line when measured from a source on Earth is 115.00 nm.

(a) Outline **one** reason for the difference in wavelength. [1]

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(b) Determine the velocity of the galaxy relative to Earth. [2]

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(Option D continues on the following page)

(Option D continued)

20. (a) The Sun is a second generation star. Outline, with reference to the Jeans criterion (M_J), how the Sun is likely to have been formed. [4]

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(b) Suggest how fluctuations in the cosmic microwave background (CMB) radiation are linked to the observation that galaxies collide. [3]

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(c) Show that the critical density of the universe is

$$\frac{3H^2}{8\pi G}$$

where H is the Hubble parameter and G is the gravitational constant. [3]

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End of Option D