Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 3

Friday 11 May 2018 (morning)

1 hour 15 minutes

Candidate session number

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 – 2

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Relativity	3 – 7
Option B — Engineering physics	8 – 11
Option C — Imaging	12 – 14
Option D — Astrophysics	15 – 19

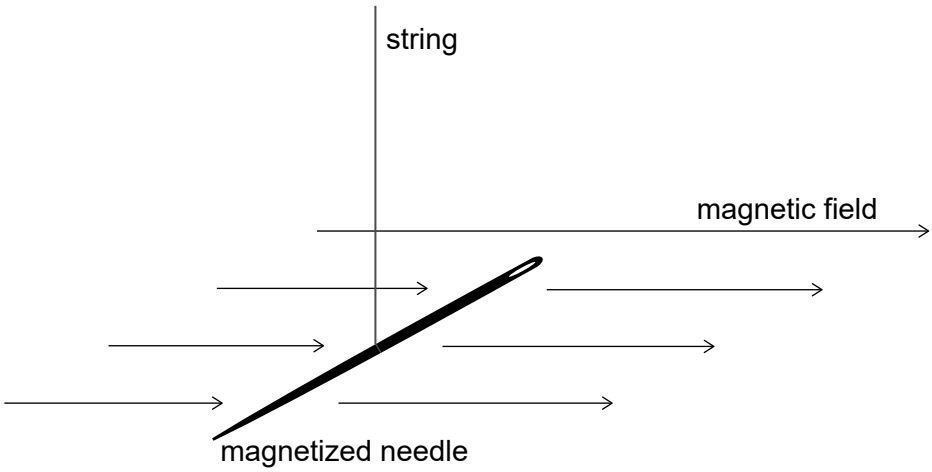
2218 – 6509

36 pages

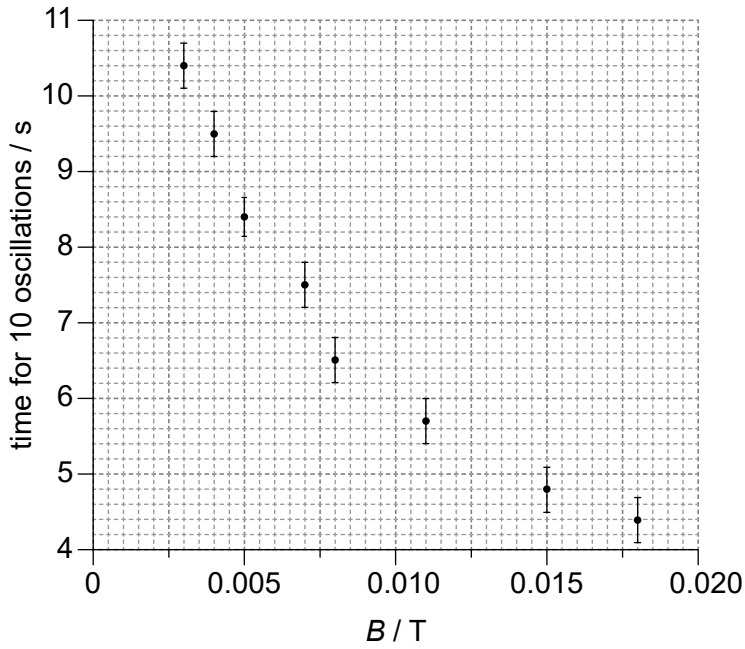
Section A

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

1. A magnetized needle is oscillating on a string about a vertical axis in a horizontal magnetic field *B*. The time for 10 oscillations is recorded for different values of *B*.



The graph shows the variation with *B* of the time for 10 oscillations together with the uncertainties in the time measurements. The uncertainty in *B* is negligible.



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

(This question continues on the following page)

(Question 1 continued)

(b) (i) Write down the time taken for one oscillation when $B = 0.005\,\text{T}$ with its absolute uncertainty. [1]

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(ii) A student forms a hypothesis that the period of one oscillation P is given by:

$$P = \frac{K}{\sqrt{B}}$$

where K is a constant.

Determine the value of K using the point for which $B = 0.005\,\text{T}$.
State the uncertainty in K to an appropriate number of significant figures. [3]

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(iii) State the unit of K. [1]

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(This question continues on the following page)

(Question 1 continued)

(c) The student plots a graph to show how P^2 varies with $\frac{1}{B}$ for the data.

Sketch the shape of the expected line of best fit on the axes below assuming that the relationship $P = \frac{K}{\sqrt{B}}$ is verified. You do **not** have to put numbers on the axes. [2]

(d) State how the value of K can be obtained from the graph. [1]

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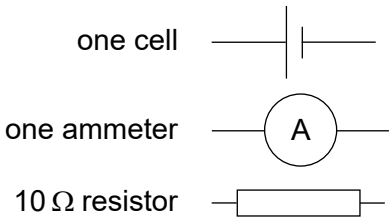
2. An experiment to find the internal resistance of a cell of known emf is to be set.
The following equipment is available:



(a) Draw a suitable circuit diagram that would enable the internal resistance to be determined. [1]

(b) It is noticed that the resistor gets warmer. Explain how this would affect the calculated value of the internal resistance. [3]

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(c) Outline how using a variable resistance could improve the accuracy of the value found for the internal resistance. [2]

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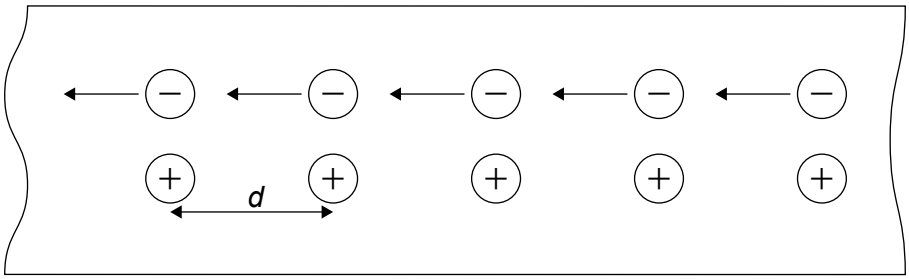
Section B

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

Option A — Relativity

3. The diagram shows the motion of the electrons in a metal wire carrying an electric current as seen by an observer X at rest with respect to the wire. The distance between adjacent positive charges is *d*.



(a) State whether the field around the wire according to observer X is electric, magnetic or a combination of both. [1]

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(b) Observer Y is at rest with respect to the electrons.

(i) Discuss the change in *d* according to observer Y. [2]

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(ii) Deduce whether the overall field around the wire is electric, magnetic or a combination of both according to observer Y. [2]

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(Option A continues on the following page)

(Option A continued)

4. Muons are created in the upper atmosphere of the Earth at an altitude of 10 km above the surface. The muons travel vertically down at a speed of 0.995*c* with respect to the Earth. When measured at rest the average lifetime of the muons is 2.1 μs.

(a) (i) Calculate, according to Galilean relativity, the time taken for a muon to travel to the ground. [1]

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(ii) Deduce why only a small fraction of the total number of muons created is expected to be detected at ground level according to Galilean relativity. [1]

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(b) (i) Calculate, according to the theory of special relativity, the time taken for a muon to reach the ground in the reference frame of the muon. [2]

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(ii) Discuss how your result in (b)(i) and the outcome of the muon decay experiment support the theory of special relativity. [2]

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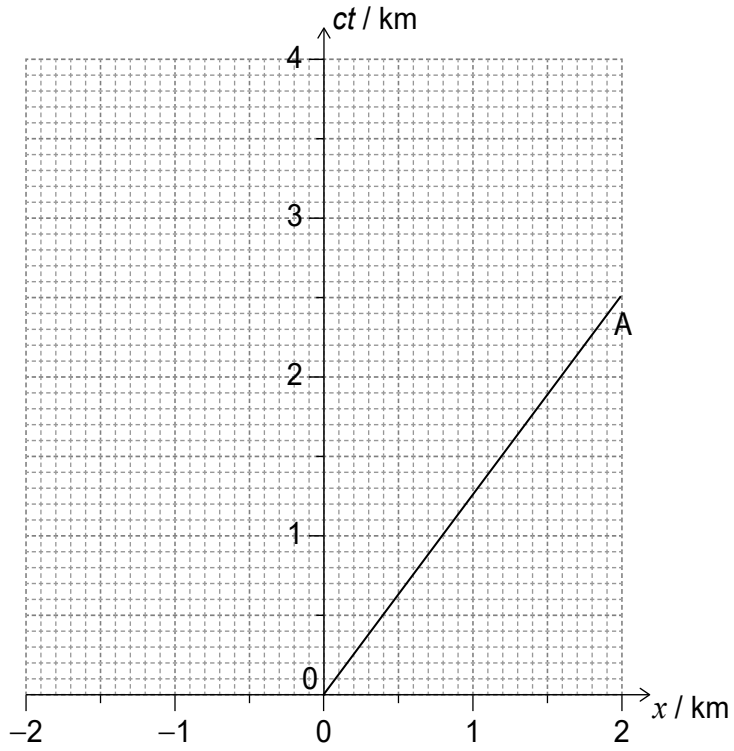
(Option A continues on the following page)

(Option A continued)

5. An observer on Earth watches rocket A travel away from Earth at a speed of 0.80*c*. The spacetime diagram shows the worldline of rocket A in the frame of reference of the Earth observer who is at rest at $x = 0$.



Another rocket, B, departs from the same location as A but later than A at $ct = 1.2\,\text{km}$ according to the Earth observer. Rocket B travels at a constant speed of 0.60*c* in the opposite direction to A according to the Earth observer.

(a) Draw on the spacetime diagram the worldline of B according to the Earth observer and label it B. [2]

(Option A continues on the following page)

(Option A, question 5 continued)

Rocket A and rocket B both emit a flash of light that are received simultaneously by the Earth observer. Rocket A emits the flash of light at a time coordinate $ct = 1.8\,\text{km}$ according to the Earth observer.

(b) Deduce, showing your working on the spacetime diagram, the value of ct according to the Earth observer at which the rocket B emitted its flash of light. [3]

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(c) Explain whether or not the arrival times of the two flashes in the Earth frame are simultaneous events in the frame of rocket A. [2]

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(d) Calculate the velocity of rocket B relative to rocket A. [2]

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(Option A continues on page 11)

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Answers written on this page
will not be marked.

(Option A continued)

6. A positive pion decays into a positive muon and a neutrino.

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

The momentum of the muon is measured to be $29.8\,\text{MeV}\,c^{-1}$ in a laboratory reference frame in which the pion is at rest. The rest mass of the muon is $105.7\,\text{MeV}\,c^{-2}$ and the mass of the neutrino can be assumed to be zero.

(a) For the laboratory reference frame

(i) write down the momentum of the neutrino. [1]

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(ii) show that the energy of the pion is about 140 MeV. [2]

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(b) State the rest mass of the pion with an appropriate unit. [1]

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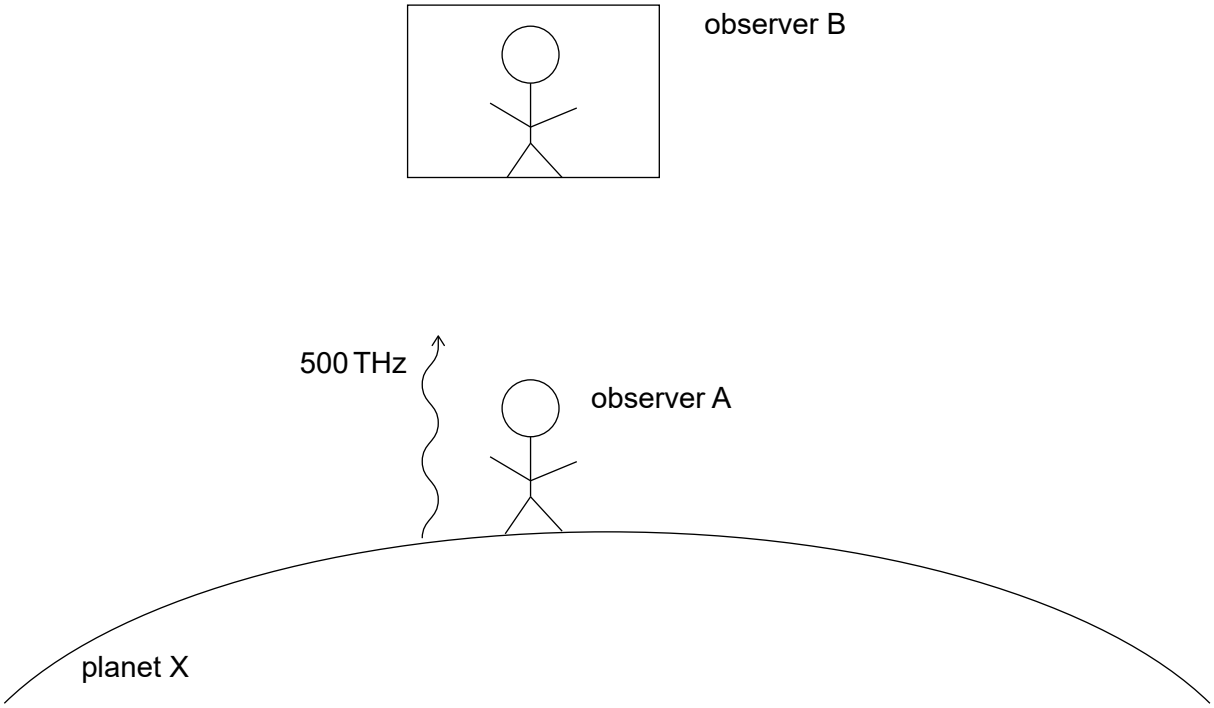
(Option A continues on the following page)

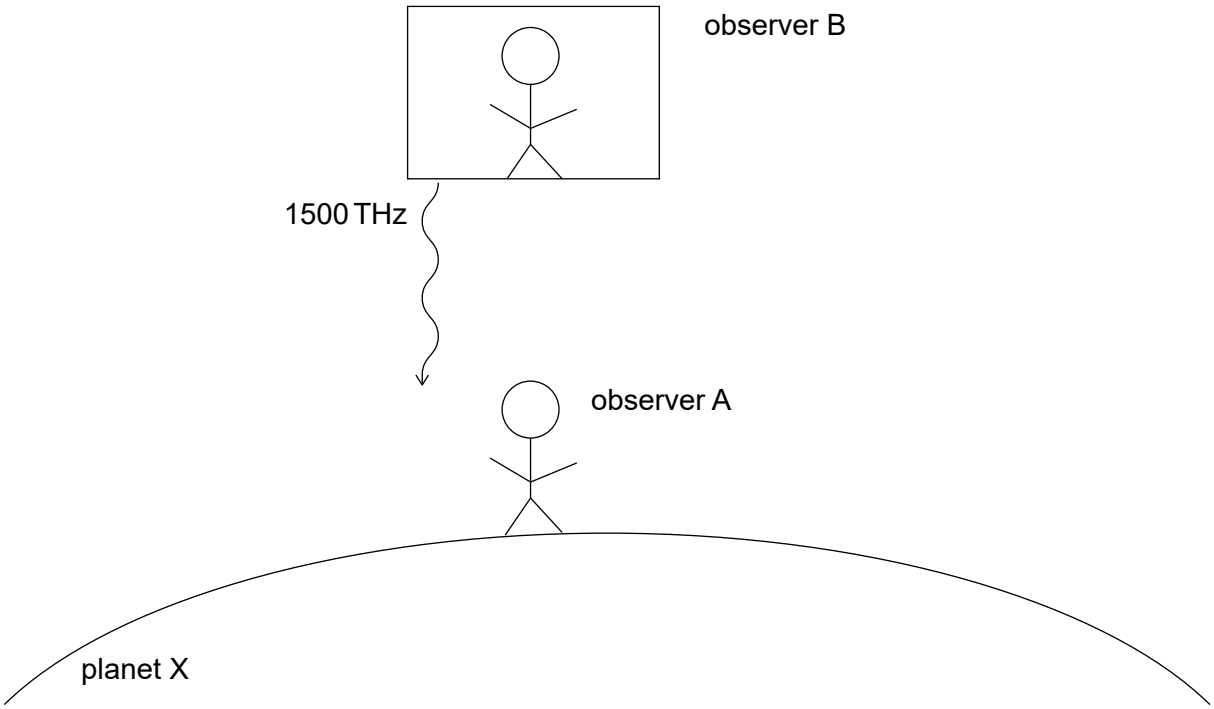
(Option A continued)

7. An observer A is on the surface of planet X. Observer B is in a stationary spaceship above the surface of planet X.

Observer A sends a beam of light with a frequency 500 THz towards observer B.
When observer B receives the light he observes that the frequency has changed by Δf.



Observer B then sends a signal with frequency 1500 THz towards observer A.



(Option A continues on the following page)

(Option A, question 7 continued)

(a) Calculate the shift in frequency observed by A in terms of Δf. [2]

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(b) Calculate the gravitational field strength on the surface of planet X.

The following data is given:
$\Delta f = 170\,\text{Hz}$.

The distance between observer A and B is 10 km. [2]

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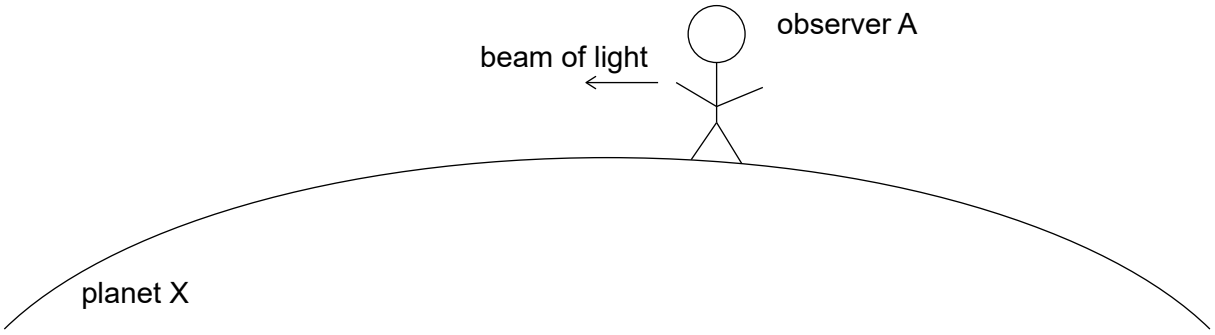
(c) Observer A now sends a beam of light initially parallel to the surface of the planet.



Explain why the path of the light is curved. [2]

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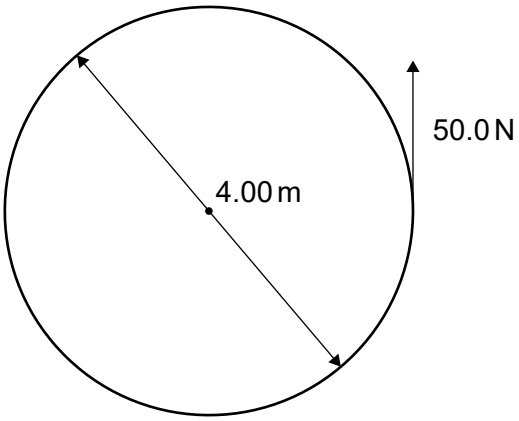
End of Option A

Option B — Engineering physics

8. A constant force of 50.0 N is applied tangentially to the outer edge of a merry-go-round. The following diagram shows the view from above.



The merry-go-round has a moment of inertia of 450 kg m^2 about a vertical axis. The merry-go-round has a diameter of 4.00 m.

(a) Show that the angular acceleration of the merry-go-round is 0.2 rad s^{-2}. [2]

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(b) The merry-go-round starts from rest and the force is applied for one complete revolution.

Calculate, for the merry-go-round after one revolution,

(i) the angular speed. [1]

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(Option B continues on the following page)

(Option B, question 8 continued)

(ii) the angular momentum. [1]

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A child of mass 30.0 kg is now placed onto the edge of the merry-go-round. No external torque acts on the system.

(c) Calculate the new angular speed of the rotating system. [2]

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(d) The child now moves towards the centre.

(i) Explain why the angular speed will increase. [2]

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(ii) Calculate the work done by the child in moving from the edge to the centre. [2]

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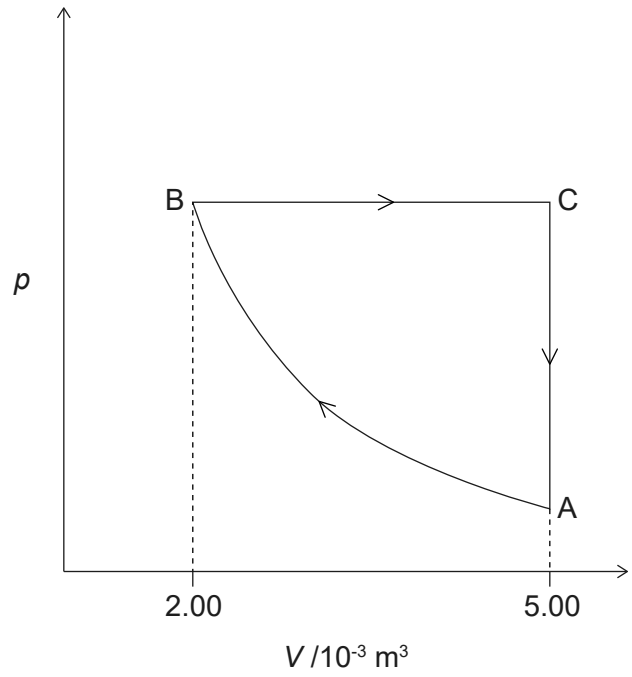
(Option B continues on the following page)

(Option B continued)

9. The pressure–volume (pV) diagram shows a cycle ABCA of a heat engine. The working substance of the engine is 0.221 mol of ideal monatomic gas.

diagram not to scale



At A the temperature of the gas is 295 K and the pressure of the gas is 1.10×10^5 Pa. The process from A to B is adiabatic.

(a) Show that the pressure at B is about 5×10^5 Pa. [2]

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(b) For the process BC, calculate, in J,

(i) the work done by the gas. [1]

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(Option B continues on the following page)

(Option B, question 9 continued)

(ii) the change in the internal energy of the gas. [1]

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(iii) the thermal energy transferred to the gas. [1]

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(c) The process from B to C is replaced by an isothermal process in which the initial state is the same and the final volume is $5.00 \times 10^{-3} m^3$.

(i) Explain, without any calculation, why the pressure after this change would be lower if the process was isothermal. [2]

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(ii) Determine, without any calculation, whether the net work done by the engine during one full cycle would increase or decrease. [2]

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(d) Outline why an efficiency calculation is important for an engineer designing a heat engine. [1]

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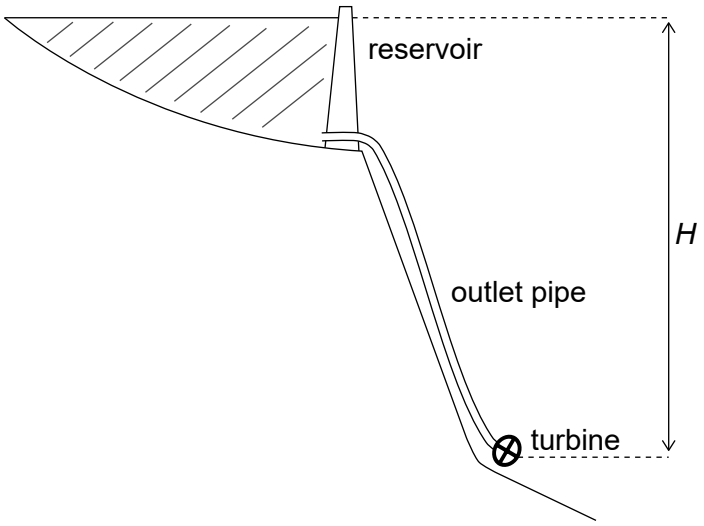
(Option B continues on the following page)

(Option B continued)

10. The water supply for a hydroelectric plant is a reservoir with a large surface area. An outlet pipe takes the water to a turbine.



(a) State the difference in terms of the velocity of the water between laminar and turbulent flow. [1]

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(b) The water level is a height H above the turbine. Assume that the flow is laminar in the outlet pipe.

Show, using the Bernouilli equation, that the speed of the water as it enters the turbine is given by $v = \sqrt{2gH}$. [3]

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(Option B continues on the following page)

(Option B, question 10 continued)

(c) The following data are available:

density of water	$= 1.00 \times 10^3\,\text{kg m}^{-3}$
viscosity of water	$= 1.31 \times 10^{-3}\,\text{Pa s}$
diameter of the outlet pipe	$= 0.600\,\text{m}$
velocity of water at outlet pipe	$= 59.4\,\text{ms}^{-1}$

(i) Calculate the Reynolds number for the water flow. [1]

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(ii) Outline whether it is reasonable to assume that flow is laminar in this situation. [1]

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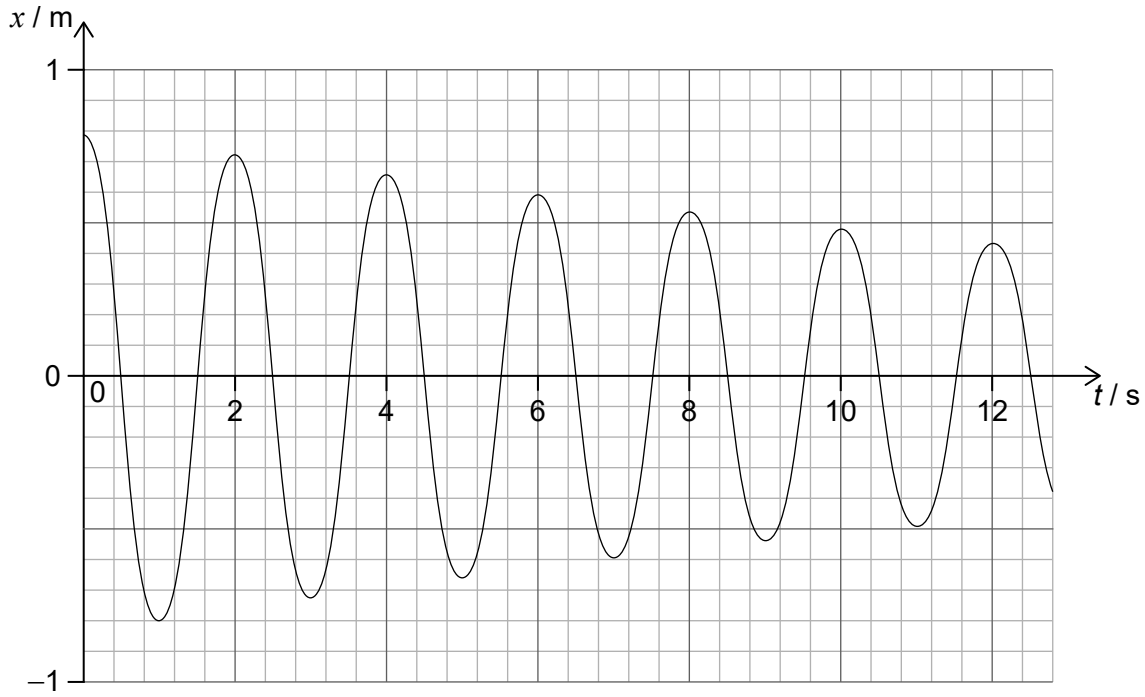
(Option B continues on the following page)

(Option B continued)

11. The graph below represents the variation with time t of the horizontal displacement x of a mass attached to a vertical spring.



(a) Describe the motion of the spring-mass system. [1]

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(b) The total mass for the oscillating system is 30 kg. For this system

(i) determine the initial energy. [1]

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(Option B continues on the following page)

(Option B, question 11 continued)

(ii) calculate the Q at the start of the motion. [2]

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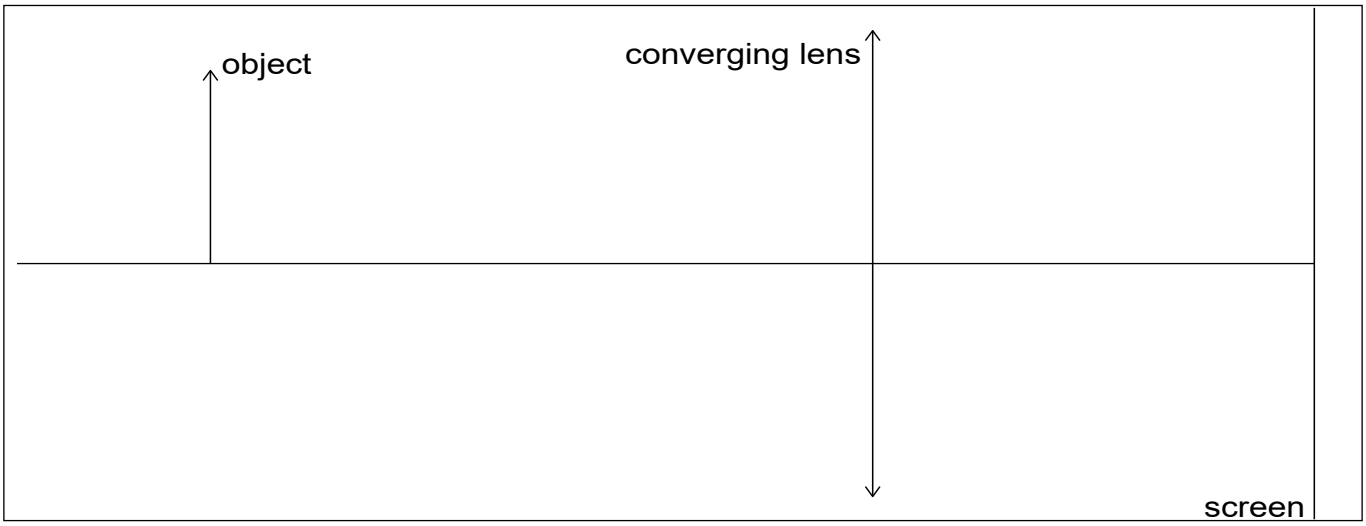
End of Option B

Option C — Imaging

12. (a) A converging (convex) lens forms an image of an object on a screen.

diagram not to scale



(i) Identify whether the image is real or virtual. [1]

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(ii) The lens is 18 cm from the screen and the image is 0.40 times smaller than the object. Calculate the power of the lens, in cm^{-1}. [3]

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(iii) Light passing through this lens is subject to chromatic aberration. Discuss the effect that chromatic aberration has on the image formed on the screen. [3]

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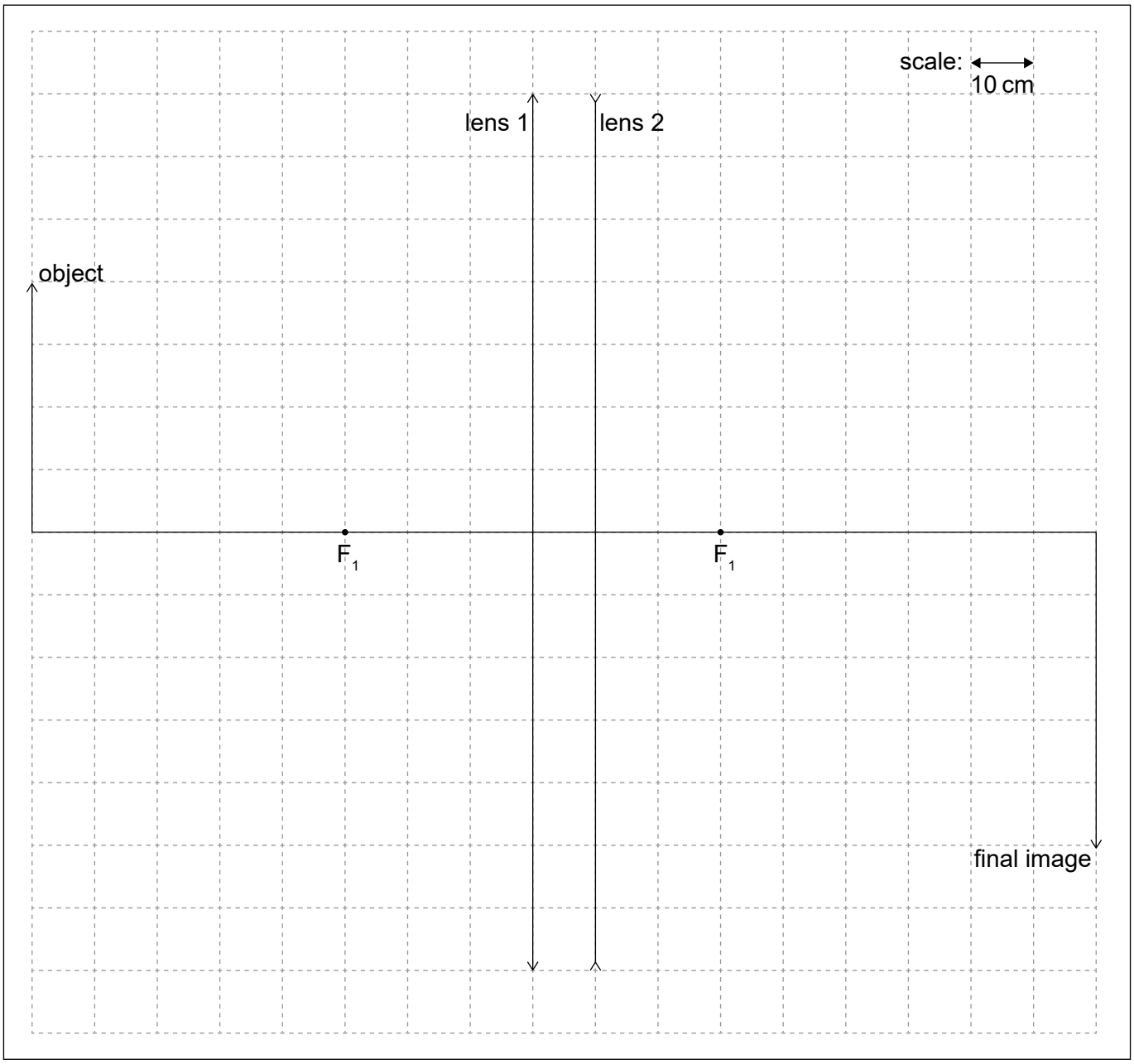
(Option C continues on the following page)

(Option C, question 12 continued)

(b) A system consisting of a converging lens of focal length F_1 (lens 1) and a diverging lens (lens 2) are used to obtain the image of an object as shown on the scaled diagram. The focal length of lens 1 (F_1) is 30 cm.



Determine, using the ray diagram, the focal length of the diverging lens. [3]

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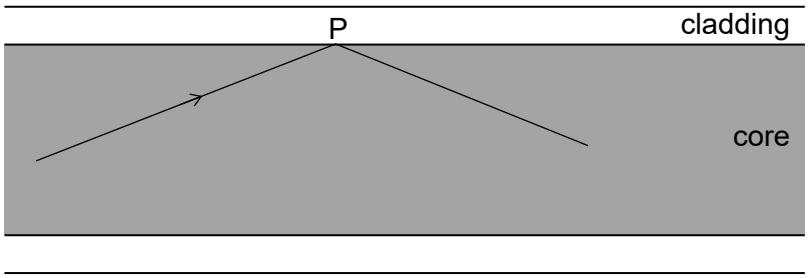
(Option C continues on the following page)

(Option C continued)

13. A ray of light travelling in an optic fibre undergoes total internal reflection at point P.



The refractive index of the core is 1.56 and that of the cladding 1.34.

(a) Calculate the critical angle at the core−cladding boundary. [1]

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(b) The use of optical fibres has led to a revolution in communications across the globe. Outline **two** advantages of optical fibres over electrical conductors for the purpose of data transfer. [2]

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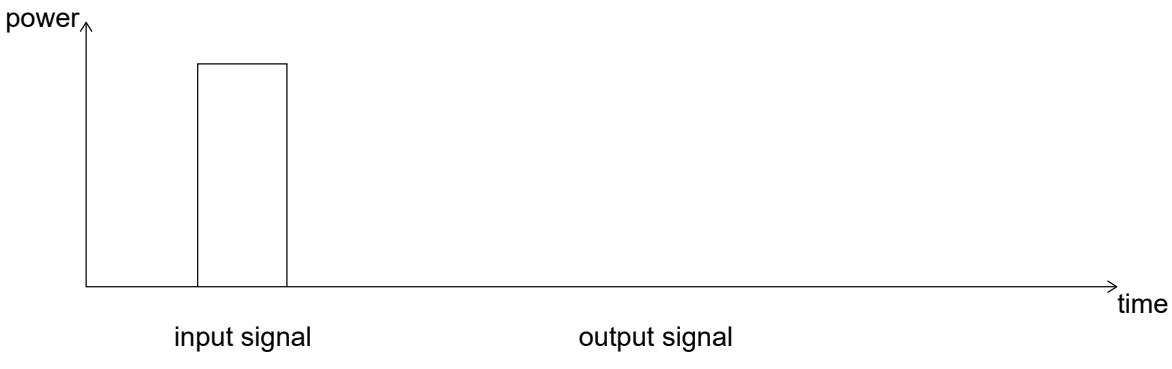
(c) The input signal in the fibre has a power of 15.0 mW and the attenuation per unit length is 1.24 dB km^{-1}

(i) Draw on the axes an output signal to illustrate the effect of waveguide dispersion. [1]



(Option C continues on the following page)

(Option C, question 13 continued)

(ii) Calculate the power of the output signal after the signal has travelled a distance of 3.40 km in the fibre. [3]

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(iii) Explain how the use of a graded-index fibre will improve the performance of this fibre optic system. [3]

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(Option C continues on the following page)

(Option C continued)

14. (a) Outline how ultrasound is generated for medical imaging. [2]

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(b) Describe **one** advantage and **one** disadvantage of using high frequencies ultrasound over low frequencies ultra sound for medical imaging. [2]

Advantage: . . . . . .

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Disadvantage: . . . . . .

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(c) Suggest **one** reason why doctors use ultrasound rather than X-rays to monitor the development of a fetus. [1]

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(Option C continues on the following page)

(Option C, question 14 continued)

(d) The table shows the speed of ultrasound and the acoustic impedance for different media.

	speed of ultrasound / m s^{-1}	**acoustic impedance / kg m^{-2} s^{-1}**
air	3.33×10^2	4.30×10^2
gel	1.48×10^3	1.48×10^6
skin	1.73×10^3	1.99×10^6

The fraction F of the intensity of an ultrasound wave reflected at the boundary between two media having acoustic impedances Z_1 and Z_2 is given by $F = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$.

(i) Calculate the density of skin. [1]

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(ii) Explain, with appropriate calculations, why a gel is used between the transducer and the skin. [4]

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End of Option C

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will not be marked.

Option D — Astrophysics

15. (a) Distinguish between

(i) the solar system and a galaxy. [1]

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(ii) a planet and a comet. [1]

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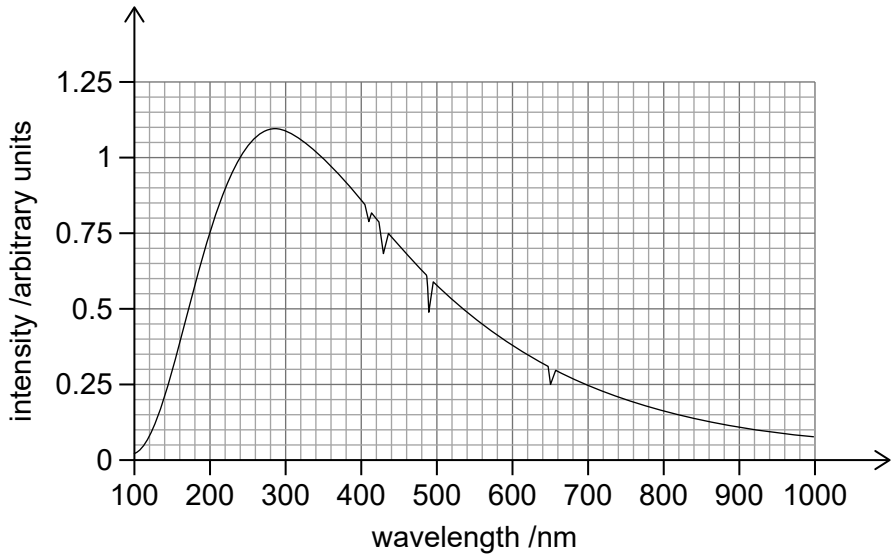
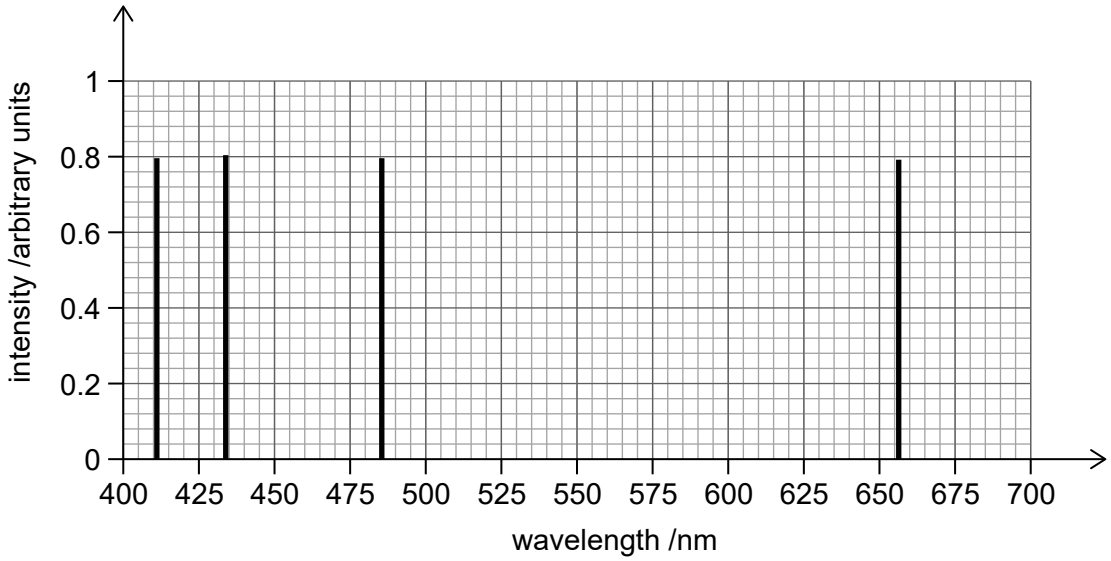
(Option D continues on the following page)

(Option D continued)

16. The graph shows the observed spectrum from star X.



The second graph shows the hydrogen emission spectrum in the visible range.



(a) (i) Suggest, using the graphs, why star X is most likely to be a main sequence star. [2]

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(Option D continues on the following page)

(Option D, question 16 continued)

(ii) Show that the temperature of star X is approximately 10 000 K. [2]

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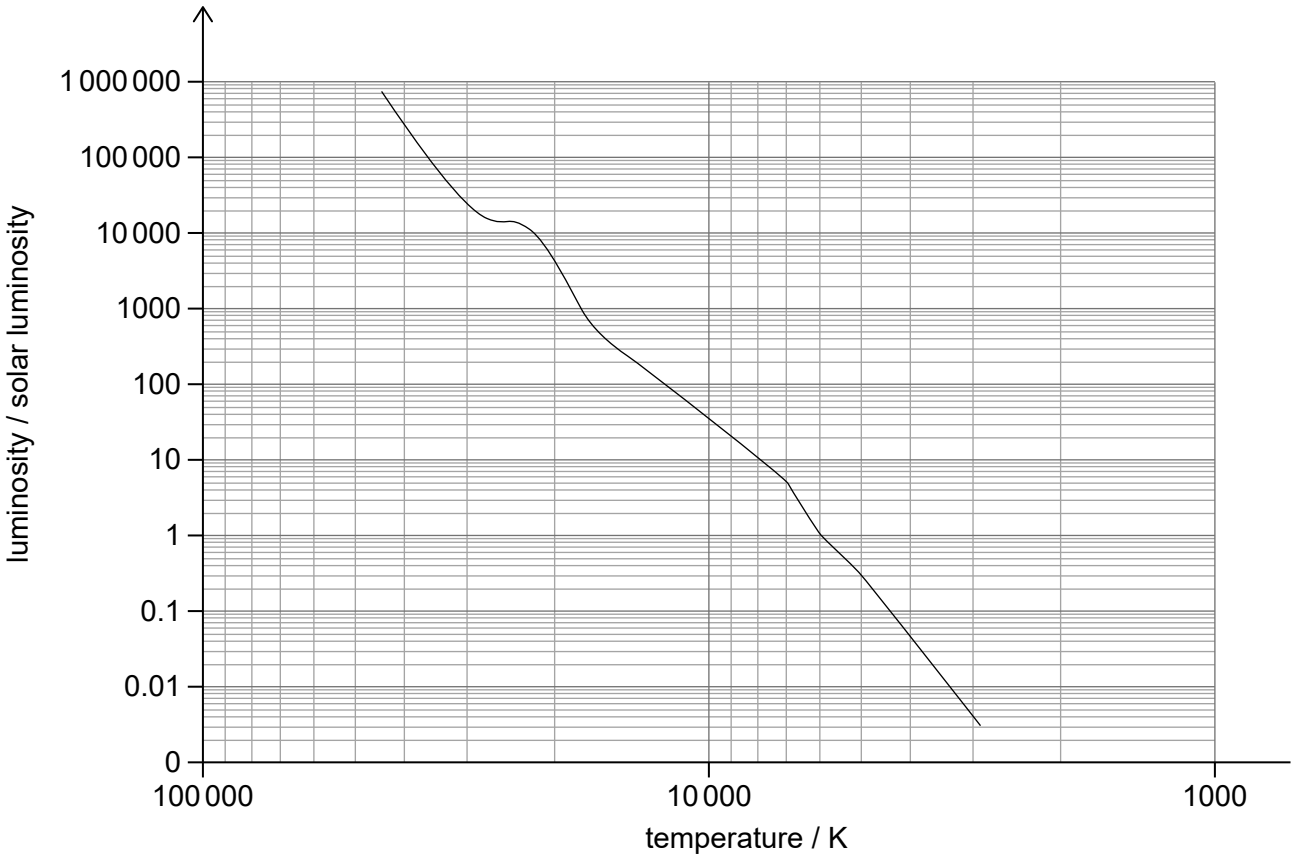
(b) The following diagram shows the main sequence.



(i) Write down the luminosity of star X (L_X) in terms of the luminosity of the Sun (L_s). [1]

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(Option D continues on the following page)

(Option D, question 16 continued)

(ii) Determine the radius of star X (R_X) in terms of the radius of the Sun (R_s). [3]

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(iii) Estimate the mass of star X (M_X) in terms of the mass of the Sun (M_s). [2]

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Star X is likely to evolve into a stable white dwarf star.

(c) Outline why the radius of a white dwarf star reaches a stable value. [2]

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(Option D continues on the following page)

(Option D continued)

17. The Hubble constant is accepted to be $70\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. This value of the Hubble constant gives an age for the universe of 14.0 billion years.

The accepted value of the Hubble constant has changed over the past decades.

(a) Explain how international collaboration has helped to refine this value. [1]

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The redshift of a galaxy is measured to be $z = 0.19$.

(b) Estimate, in Mpc, the distance between the galaxy and the Earth. [2]

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(c) Determine, in years, the approximate age of the universe at the instant when the detected light from the distant galaxy was emitted. [3]

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(Option D continues on the following page)

(Option D continued)

18. (a) Describe the formation of a type Ia supernova. [2]

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(b) Type Ia supernovae typically have a peak luminosity of around $5 \times 10^5 L_s$, where L_s is the luminosity of the Sun (3.8×10^{26} W). A type Ia supernova is observed with an apparent peak brightness of $1.6 \times 10^{-6}\,W\,m^{-2}$.

(i) Show that the distance to the supernova is approximately 3.1×10^{18} m. [2]

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(ii) State **one** assumption made in your calculation. [1]

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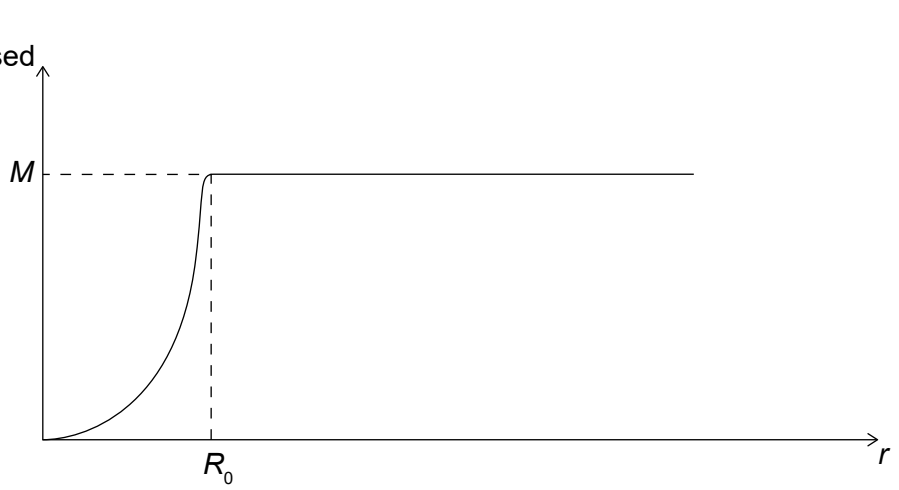
(Option D continues on the following page)

(Option D continued)

19. A galaxy can be modelled as a sphere of radius R_0. The distance of a star from the centre of the galaxy is r.



For this model the graph is a simplified representation of the variation with r of the mass of **visible matter** enclosed inside r.

(a) The mass of visible matter in the galaxy is M.

Show that for stars where $r > R_0$ the velocity of orbit is $v = \sqrt{\frac{GM}{r}}$. [1]

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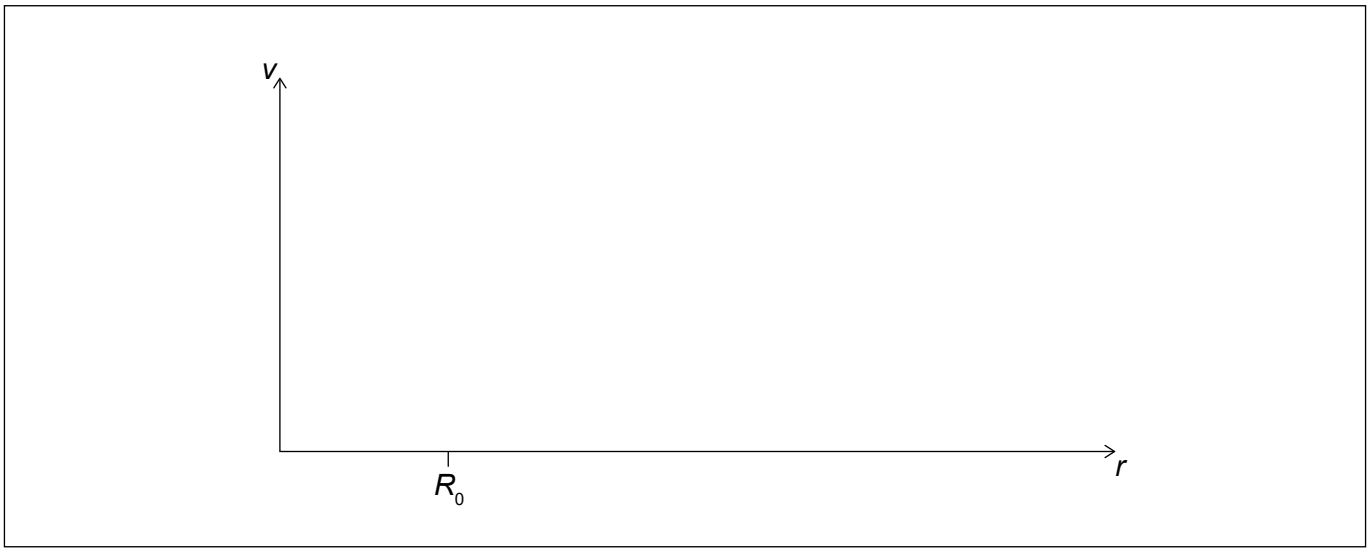
(Option D continues on the following page)

(Option D, question 19 continued)

(b) Draw on the axes the observed variation with r of the orbital speed v of stars in a galaxy. [2]



(c) Explain, using the equation in (a) and the graphs, why the presence of visible matter alone cannot account for the velocity of stars when $r > R_0$. [2]

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End of Option D